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GEOPHYSICS

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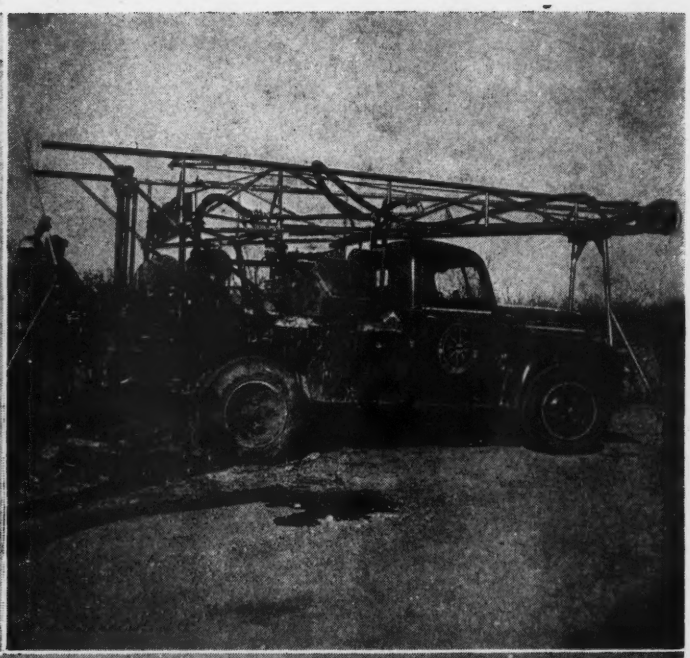

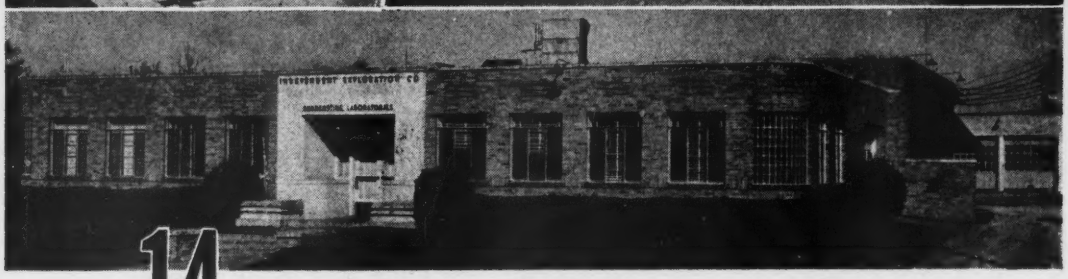

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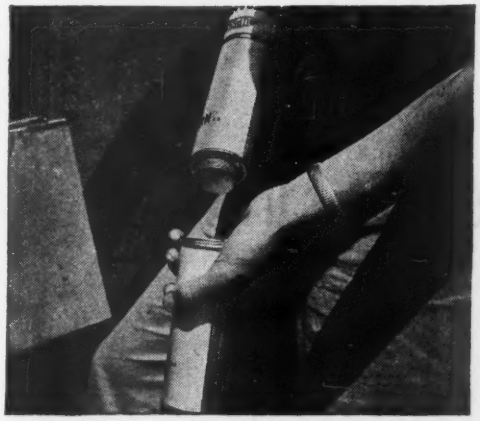

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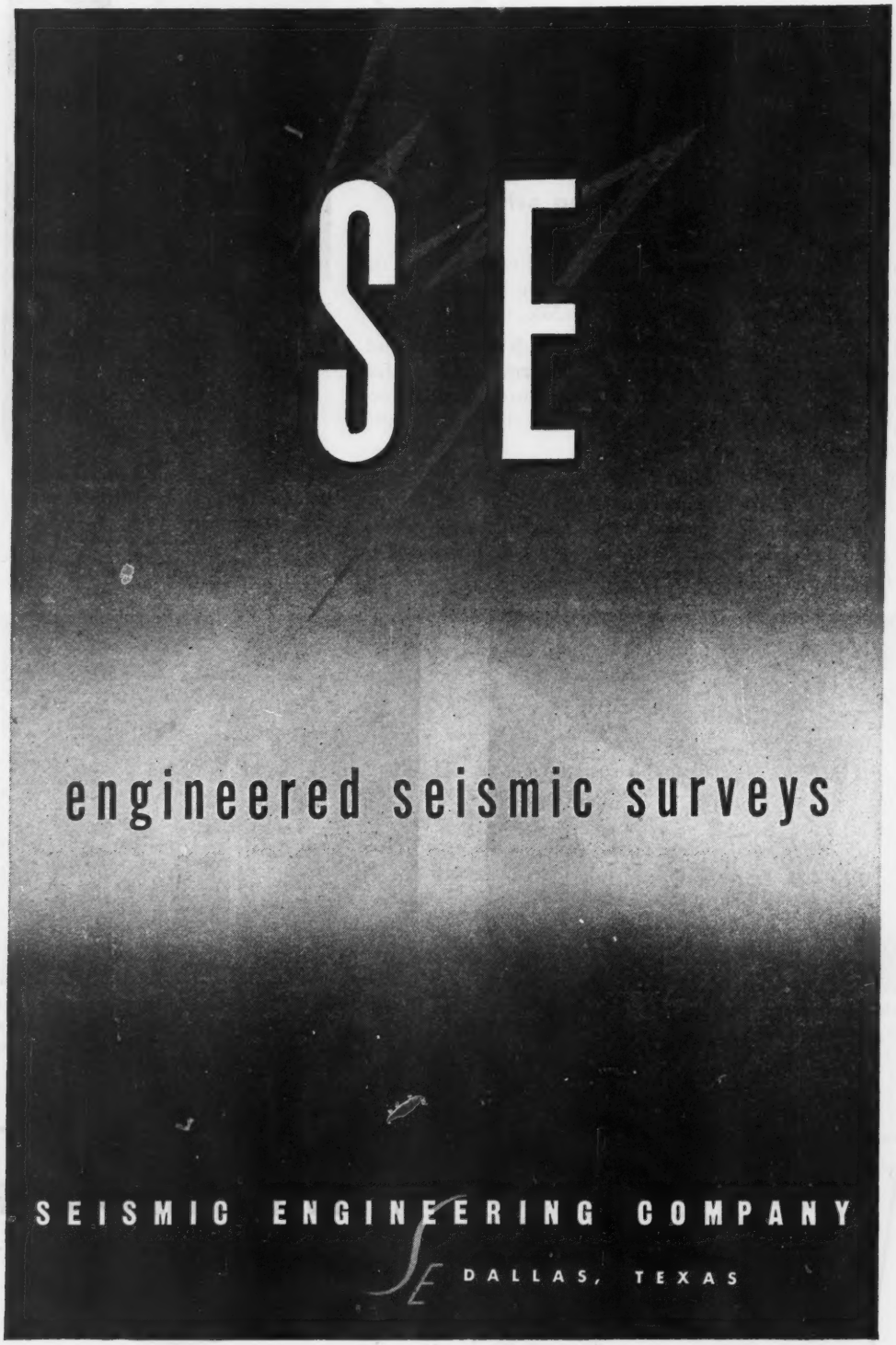
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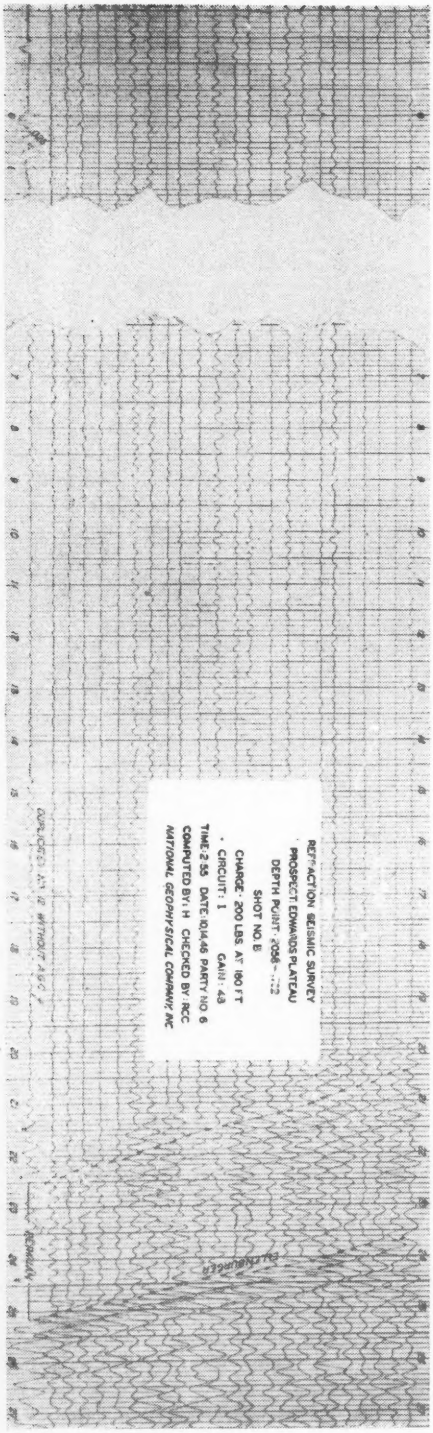
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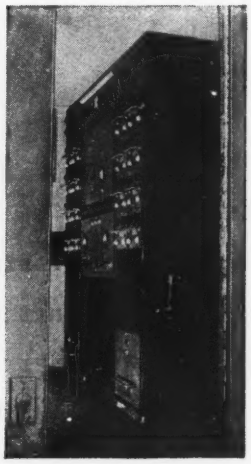

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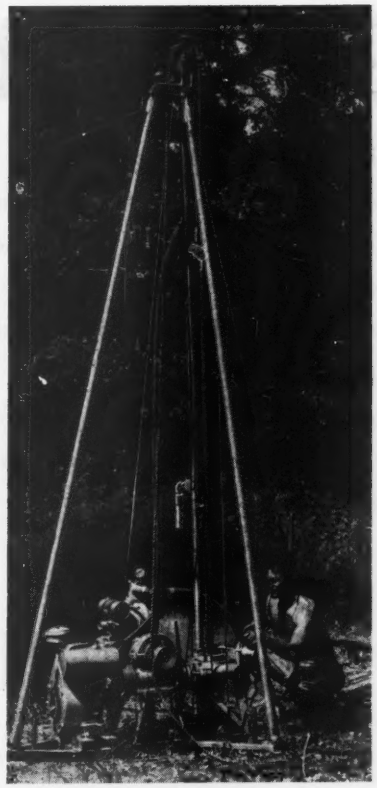

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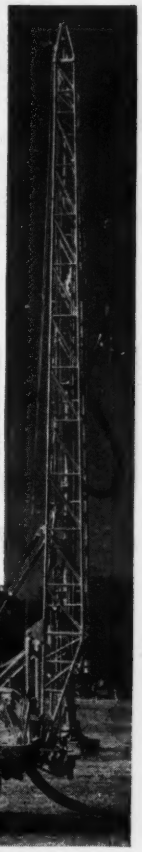

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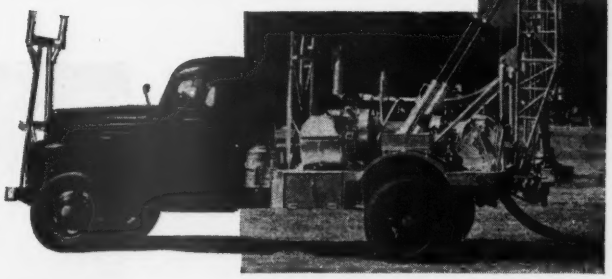

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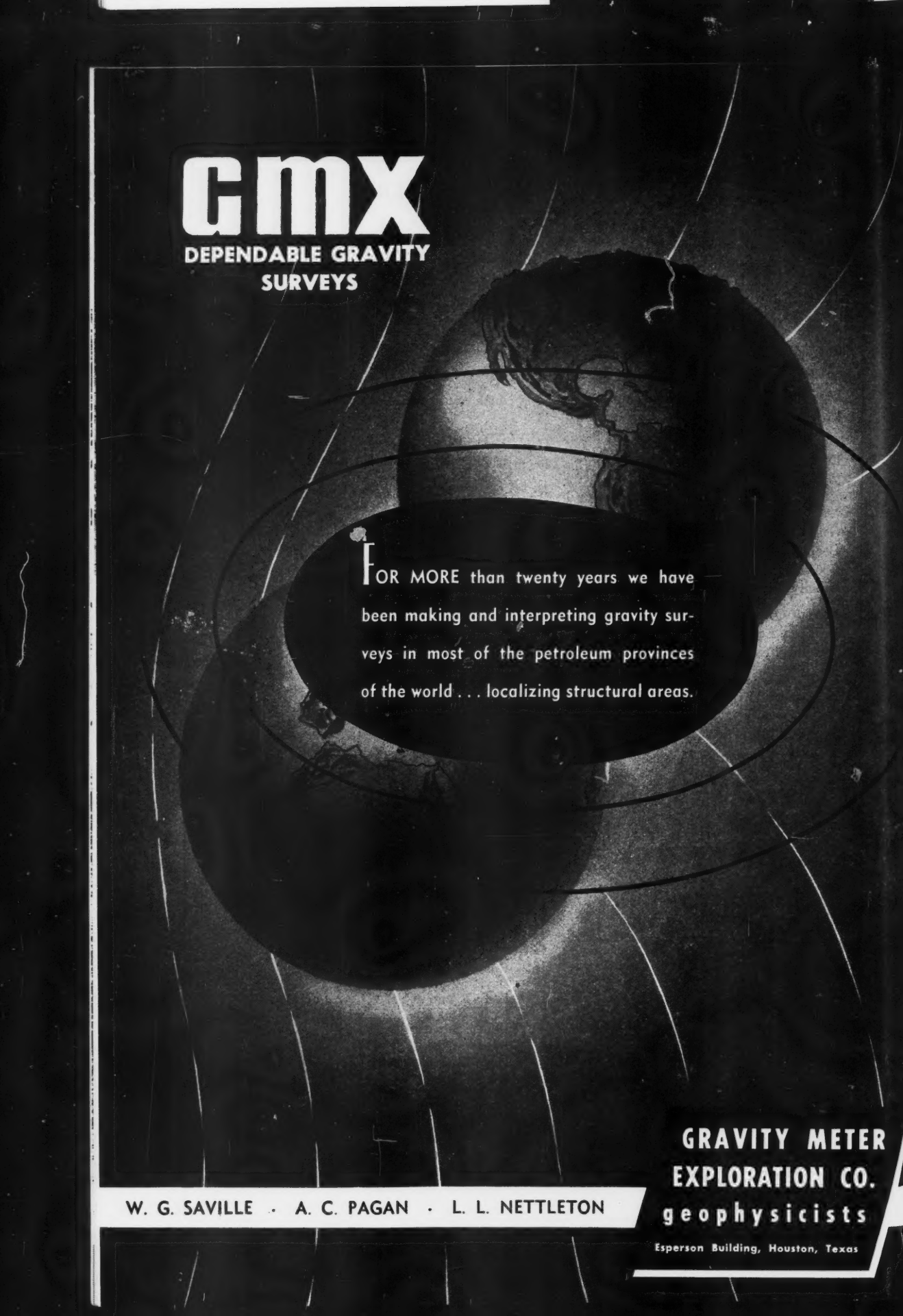
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VOLUME XII JANUARY, 1947 NUMBER 1

GEOPHYSICS

A Journal of General and Applied Geophysics

A DIVING BELL FOR UNDERWATER GRAVIMETER OPERATION*

EUGENE W. FROWE†

ABSTRACT

The recent development of a diving bell, designed to carry a gravimeter and observer, enables the geophysicist to make correct gravity observations on a river, lake or ocean floor. The bell, for which patents have been applied, is designed to operate in depths of water as great as 250 feet. It has been used with good results at depths ranging from 8 to 70 feet.

Data taken from adjacent land and sea areas have been contoured and the smoothness of the resulting contours indicates that the underwater gravity readings are entirely reliable.

Structural features of the diving bell and related equipment are described and plates showing exterior and interior views of the bell are given.

During the summer of 1944 Mr. C. F. Sellers of the Robert H. Ray Company conducted a gravimeter survey in the waters along the northern coast of Cuba. The gravimeter was operated from a tripod with good success even though the area worked was open water. Depths of water as great as eighteen feet were surveyed in this manner. An attempt to work the southern coast of Cuba with the water tripod proved unsuccessful because of the severe vibration caused by the wind, waves, and tides. This difficulty led to the construction of the geophysical diving bell which permits the gravimeter and observer to be lowered to the ocean floor for direct gravity observations. The first diving bell, designed and built by Mr. Sellers, was put in operation in December, 1944.

The use of a diving bell in making gravity surveys in water covered areas has two advantages over the use of a water tripod. First, with the proper type of equipment, any depth of water, from the shallowest to

* Read at the Chicago and Houston meetings of the Society, 1946.

† Robert H. Ray Co., Houston, Texas.

FIG. 1. Cylindrical Diving Bell. This bell has a water ballast chamber which enables the bell to be surfaced by blowing out the water ballast. Designed for water depths as great as 250 feet this bell works best at depths of 18 feet or more in waters with coral or hard sand bottom.

250 feet, can be readily surveyed. Second, wind, wave, and tidal action have little effect on gravimeter stability. There is a limiting factor here, however: The waves may become high enough to make the lowering of the bell into the water hazardous.

As far as reliability is concerned, there is no difference in gravity stations taken on land and those taken under water. The corrected

FIG. 2. Close up top view of cylindrical diving bell. Note the pipe fittings in the lower left of the picture for attaching the air lines. The center section of the lid can be removed from the inside for making an emergency escape from the bell.

gravity values of water areas, when contoured with adjacent land areas, give contours as smooth as those of a single land area.

In this paper the term "diving bell" is used to define any submersible chamber in which an observer and gravimeter are lowered to the ocean floor for direct readings there. The diving bell may be completely open on the bottom, sealed on the bottom, or equipped with holes in the bottom, which have removable covers so that a tripod may be pushed directly into the mud to isolate the bell from the gravimeter.

The most elaborate of these diving bells is one with a sealed bottom and a water ballast chamber. It will be discussed in detail in this paper, since it illustrates the problems of bell construction and use. It was first used along the southern coast of Cuba in the Gulf of Batabano, where the water varies from 15 to 62 feet in depth. The sea

floor, there, is coral. A barge 60 by 20 feet was used to transport the bell, and a crane, mounted on the barge, was used for lowering and raising the bell in the water.

Figure 1 is a picture of the diving bell, and Fig. 2 is a picture showing details of the top region. The bell consists of two concentric steel

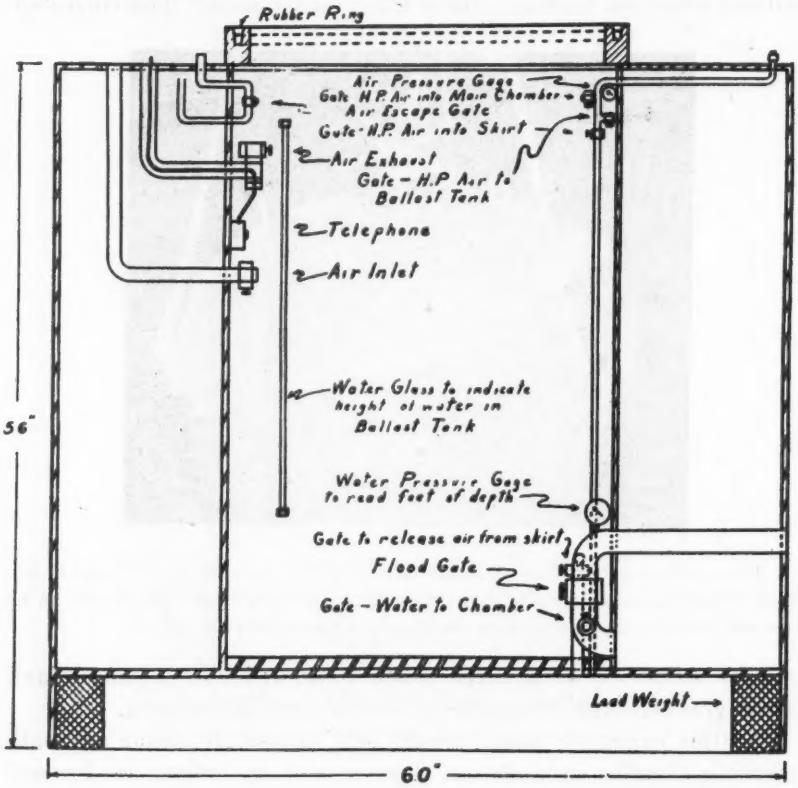

FIG. 3. Cross section of the cylindrical diving bell with lid and legs removed.

cylinders of equal length, with a strong water tight bottom welded on them. The top consists of a flat doughnut shaped steel ring, which seals the volume between the two cylinders and forms the ballast chamber. The inner cylinder is covered with a removable lid and serves to house the gravimeter and observer. The center section of the lid is removable from within the bell and serves as an escape hatch. Tripod legs support the bell when it is on the ocean floor, and a three-forked yoke supports the bell when it is being raised or lowered in the water. Fresh air is

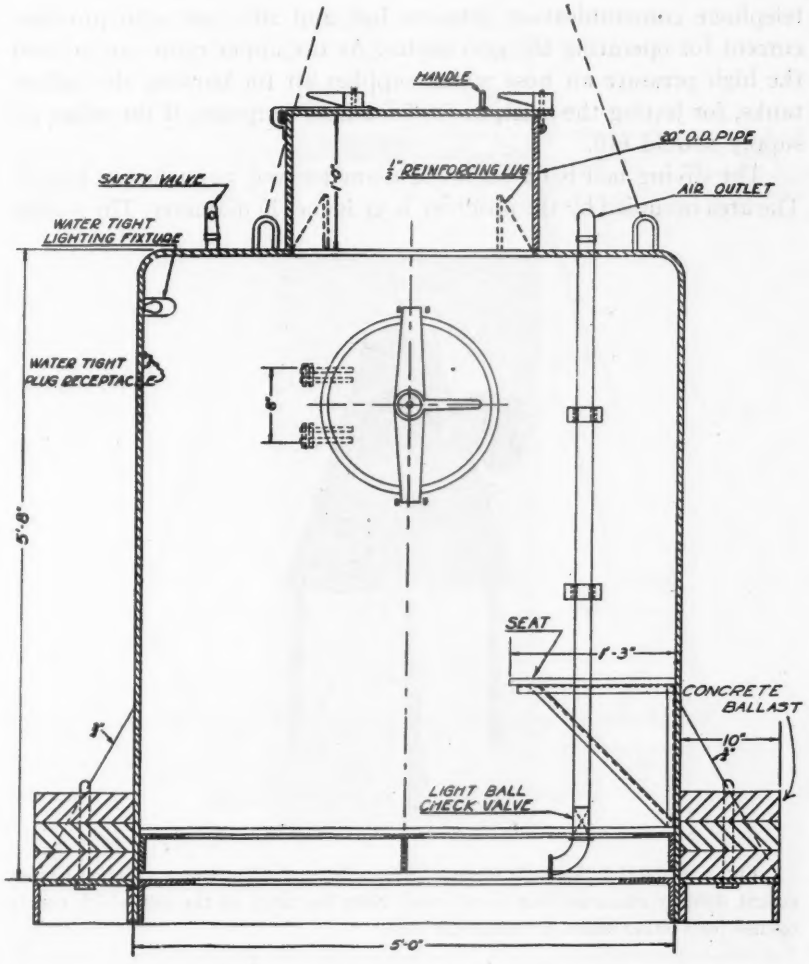

FIG. 4. Cross sectional view of the open bottom diving bell. This bell has a steel grate for a floor. Air pressure inside the bell is maintained at a slightly higher value than water pressure outside to keep water from rising in the bell. The practical limit of this bell for repeated dives is 33 feet of water.

supplied the observer through an air hose connected to the 1½ inch pipe nipples seen in the lower left of Fig. 2.

Figure 3 is a schematic cross section of the diving bell with the lid and tripod legs removed. The two 1½" air lines shown at the upper left provide the low pressure air supply and exhaust. The low pressure line in addition serves as a conduit for the electrical cable, which provides

telephone communication between bell and ship and also provides current for operating the gravimeter. At the upper right can be seen the high pressure air hose which supplies air for blowing the ballast tanks, for jetting the skirt, or for breathing purposes, if the other air supply should fail.

The diving bell is 60 inches in diameter and 50 inches in height. The area occupied by the observer is 31 inches in diameter. The weight

FIG. 5. Conical diving bell. Designed primarily for shallow water, this bell has excellent stability characteristics in soft mud. Note the hatch on the side which can be opened from either inside or outside the bell.

of the bell with observer and gravimeter is 5000 lbs. Of this, 2000 pounds is lead ballast, which is located on the inside of the skirt near the bottom. The bell, when submerged, displaced 5400 pounds of water giving the bell a net buoyancy of 400 pounds.

Before making a dive, the ship must be anchored to keep it from drifting away from the bell after the bell has been lowered. Usually a bow anchor and two side anchors are required.

Because the bell, without water ballast, is buoyant, the observer opens the lower flood valve and the upper vent valve to the ballast chamber as the bell is being lowered into the water. (See Fig. 3.) As soon as the buoyancy is overcome, the bell may be lowered the rest

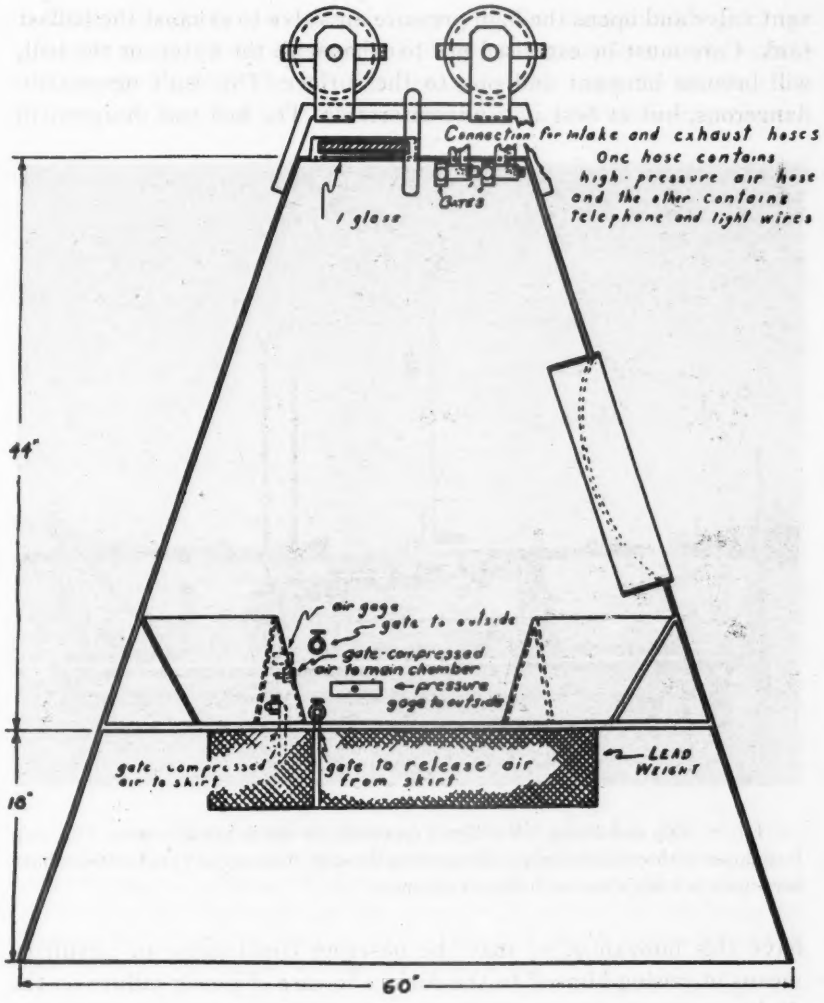

FIG. 6. Cross section view of conical diving bell.

of the way to the bottom of the sea. As the bell goes down, the observer continues to let water into the ballast tank until it is full. A glass tube water gauge tells him how much water he has in his ballast tank. After he reaches bottom, he levels his gravimeter and takes the gravity reading. A water pressure gauge in the bell enables him to determine his water depth. Two-way telephone communication enables the crew on deck to follow the progress of the dive.

After the reading has been taken, the observer closes the ballast

vent valve and opens the high pressure air valve to exhaust the ballast tank. Care must be exercised not to exhaust all the water, or the bell, will become buoyant and pop to the surface. This isn't necessarily dangerous, but at best it is uncomfortable. The bell was designed to

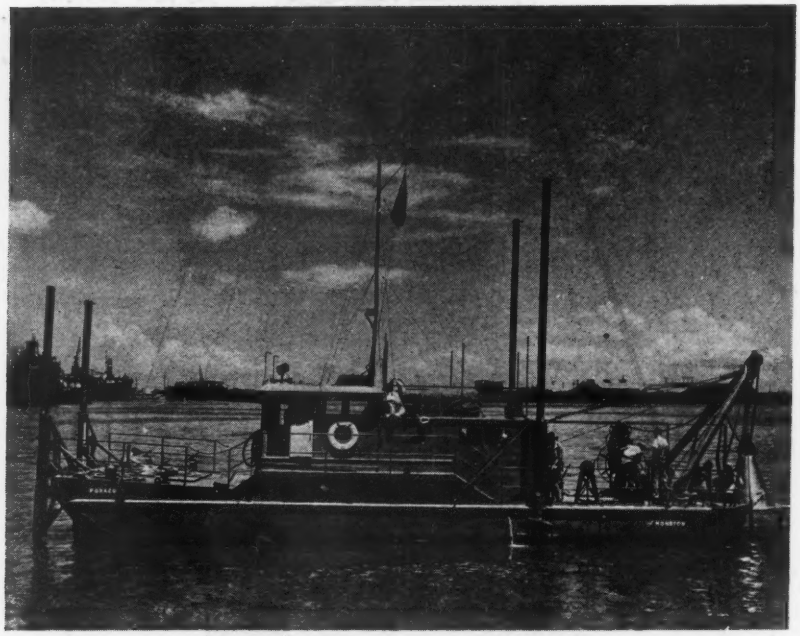

FIG. 7. Ship and diving bell designed especially for use in inland waters. This ship is equipped with spudders for quickly securing the ship. As many as 25 net stations have been made in a day's time with this arrangement.

have this buoyancy, so that the observer could have an auxuliary means of raising himself to the surface in case of power failure on the deck.

It might be well to mention, in summary, the safety features of this bell. Structurally the bell will withstand pressures encountered in 500 feet of water, although it is designed for 250 feet. Two sources of air for breathing purposes are provided, either of which will supply the observer indefinitely, since the pressure in the bell is at all times nearly atmospheric. Even if both air supplies should fail, the bell has sufficient volume to sustain the observer until the bell can be raised to the surface. If the winch should fail, the observer can blow himself to the surface with compressed air in the ballast tanks. If all these

facilities should fail, as would happen if the ship should sink, the observer can flood the inner chamber and escape to the surface through the escape hatch in the lid. For deeper depths a special escape lung, similar to those used in submarines, will be provided. Experienced

FIG. 8. This picture shows the *Poraco I* rigged with the conical diving bell. This type bell works well in mud and has unusually good stability. The observer and gravimeter are in the diving bell and the bell is being lowered for a reading. Note the bow line and the stern lines which are connected to anchors for securing the ship during this operation. Visible near the American flag are two signal spheres which warn passing ships that the ship is at anchor and that a diver is down.

navy trained divers supervise diving operations and are always ready to take a line to the bell, in the event that the lines should become fouled.

The diving bell may appear top-heavy with safety features and perhaps it is. But it is interesting to note that no one who is familiar with the bell and has seen it in operation is afraid to make a dive in the bell.

Because of its weight and safety features, this bell is particularly suited for areas where the water depth is 15 feet or greater and where there is a sand, clay, or coral bottom.

A second type diving bell, designed by our Mr. V. W. Humphrey has an open bottom. (See Fig. 4.) It was used in the northern end of Lake Maracaibo, where wind and rough water made tripod gravity observations difficult. The lake floor in this region is sand, and depths

FIG. 9. This picture is a close-up of the conical diving bell secured to the stern of the *Poraco I.*

as great as 22 feet were explored. The practical limit on this type bell is 33 feet, because air pressure in the bell must be slightly greater than the water pressure outside the bell, and at greater depths decompression must be used for the observer and only a limited number of dives may be made in a day's time.

A third type diving bell which has been developed by this company is particularly suited for shallow water work. This diving bell does not have the ballast chamber, as the larger bell has, but it is simple, light in weight, and safe for depths not exceeding sixty feet. Fig. 5 is a picture of the shallow water bell, and Fig. 6 is a schematic cut away. Note the conical shape of the bell, the escape hatch on the side, and the absence of the ballast tank. This bell is well suited for soft mud because it has a broad base, a low center of gravity, and a low profile,

which renders it less sensitive to wave and tide action. A more versatile version of this bell has the lead ballast fastened to the skirt instead of on the bottom, as shown in Fig. 6. A port is cut in the bottom of the bell and covered so that normally it may be used as a closed bottom

FIG. 10. This is a picture of our latest model diving bell shown in its cradle on the stern of an all steel vessel. This type bell differs from the original conical bell in that the skirt and lead weights have been removed and in their place a 2" flat steel plate has been substituted. This causes the center of gravity of the bell to be quite low and provides a broad base which adds considerably to the bell's stability in mud covered areas.

bell. For rough water or a very soft mud the cover may be removed, and the bell operates as an open bottom bell.

By the time this bell was designed and built, we had also designed a special ship for its operation. Ship and bell are shown in Fig. 7. This arrangement gives the fastest operation in water up to 20 feet in depth because the spudders, seen at the bow and just aft of the cabin,

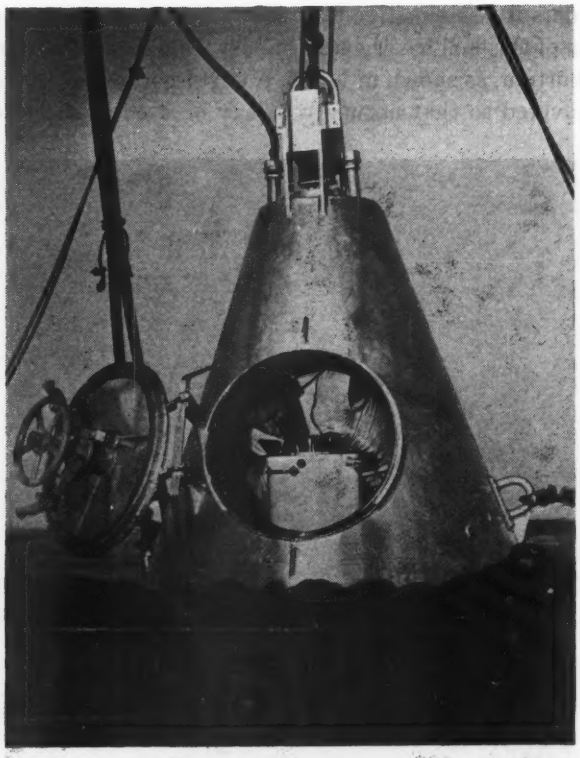

FIG. 11. The observer in this picture is in the position he assumes while actually taking a reading on the botton. Note the head phones and microphone which enable him to communicate with the crew on deck.

may be used to anchor the ship. For deeper depths up to 60 feet, anchors must be used which make operations somewhat slower. Minimum operating depth for this ship is three and one-half feet, although a similar ship is currently in operation which requires water only two and one-half feet deep.

Figures 8 to 11 are included to give further general information on the operation of the diving bell in the water.

The diving bell has proved itself a valuable aid to the geophysicist who works with gravity data, and it is believed that many underwater prospects will be located through its use.

The author wishes to thank Mr. Robert H. Ray and Mr. Jack C. Pollard for their help in preparing this paper.

THE GEOLOGY AND GEOPHYSICS OF THE ODEM OIL FIELD, SAN PATRICIO COUNTY, TEXAS*

HOLLAND McCARVER[1] AND LLOYD G. WEST[2]

ABSTRACT

The Odem field, located in southern San Patricio County, Texas, was discovered in the latter part of 1939. Prior to 1933, the Odem area received a limited amount of geological and geophysical exploration, and several test wells were drilled. These tests were dry and the area apparently condemned until a reflection seismograph survey indicated structure. Subsequent drilling confirmed the presence of a structure containing several producing horizons. The proven limits of production conformed closely to the contours of the original seismograph map.

INTRODUCTION

The discovery of the Odem field in October 1939, may be considered one of the major successes of the reflection seismograph as a method of geophysical prospecting for oil. In an area apparently condemned by eight dry exploratory tests, a reflection seismograph survey made for the Seaboard Oil Company of Delaware by Geophysical Service Incorporated, located a structure that subsequent drilling proved to be a major oil field.

LOCATION

The Odem field is located in the south central part of San Patricio County, Texas. (See Fig. 1.) The field is two miles west of Odem, the town from which it receives its name, and approximately seventeen miles northwest of the city of Corpus Christi, Nueces County, Texas.

HISTORY OF DISCOVERY

Early Exploration and Drilling: Interest in the Odem area, as a possible oil producing territory, was probably first evidenced during the development of the coastal or "railroad" trend of South Texas, and during the drilling of the Nueces County fields to the south. Several major oil companies became interested in the area and some leasing was done, but not until late in 1933 were any steps taken to-

* Presented at the sixteenth annual meeting, Chicago, Illinois, at the Regional Meeting, Houston, Texas, April, 1946, and at a regular meeting of the Dallas Geological Society in May, 1946.

[1] Seaboard Oil Company of Delaware, Dallas, Texas.

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ward drilling a test well in the area. At this time a reconnaissance geological survey, conducted by Guy E. Green for Atkins and O'Neil, mapped an inlier of the Lissie formation in southern San Patricio County, on the basis of which an exploratory test location was made just west of the town of Angelita and four miles southwest of Odem. This well, the Atkins and O'Neil No. 1 J. F. Welder (shown as No. 1

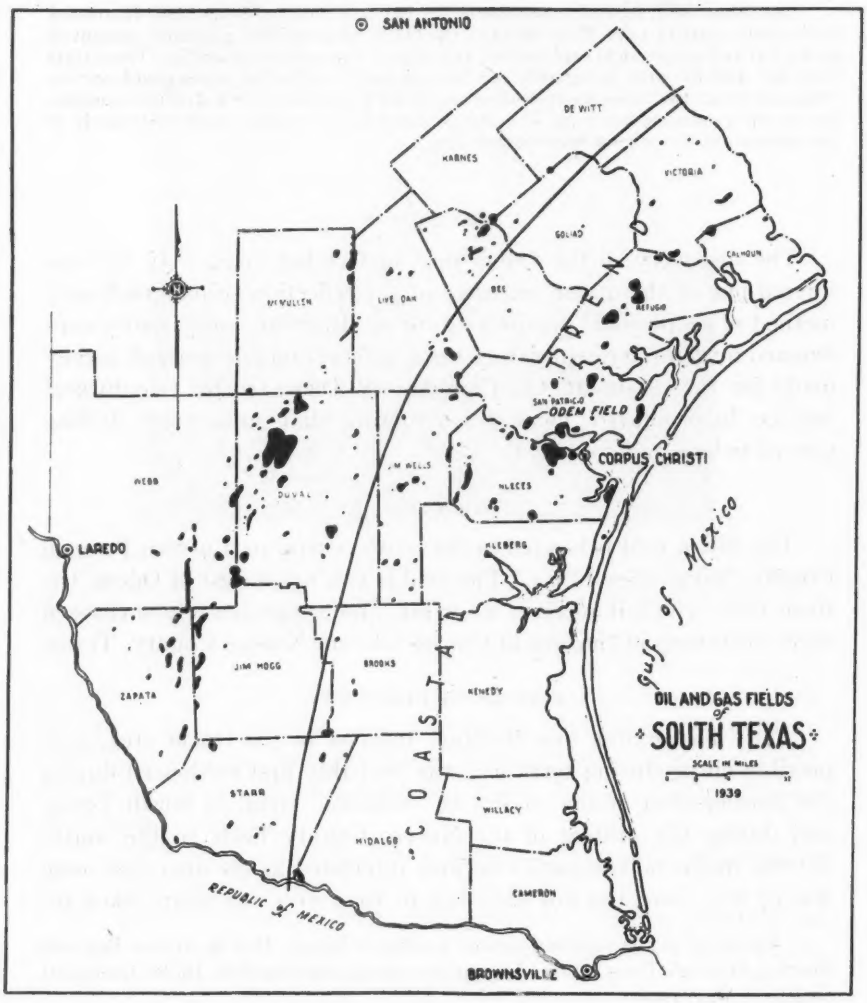

FIG. 1. Index map of South Texas showing the location of the Odem oil field, San Patricio County, Texas.

in Fig. 2 and following maps), was completed in April 1934, as a small oil well, but was subsequently abandoned. Production in this well came from the Angelita sand, forty feet above the producing Sinton

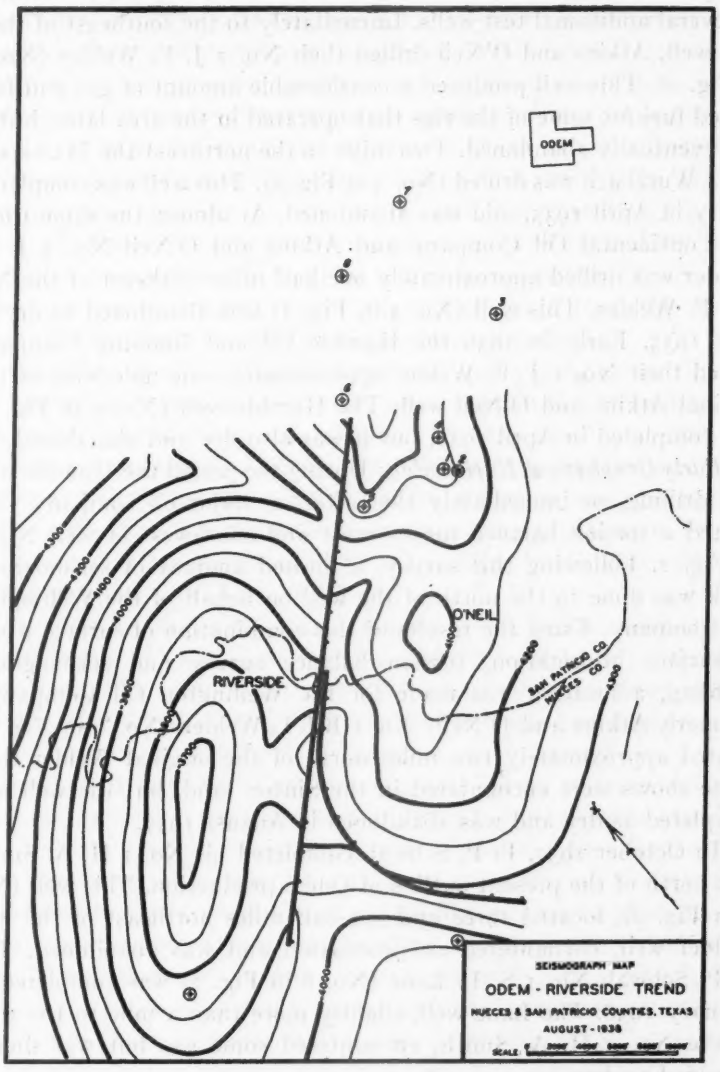

FIG. 2. Seismograph map of the Odem-Riverside area, August 1938, prior to the discovery of the Odem structure. The circled wells shown were drilled before the start of the seismograph program, and are numbered in the order in which they were drilled.

sand of the Odem field. The Angelita sand is not present in the Odem field.

The encouraging show encountered in the No. 1 J. F. Welder brought considerable attention to the area and instigated the drilling of several additional test wells. Immediately to the southeast of their first well, Atkins and O'Neil drilled their No. 2 J. F. Welder (No. 2 in Fig. 2). This well produced a considerable amount of gas and furnished fuel for some of the rigs that operated in the area later, but it was eventually abandoned. Two miles to the northeast the Masterson No. 1 Wurzbach was drilled (No. 3 in Fig. 2). This well was completed as dry in April 1935, and was abandoned. At almost the same time, the Continental Oil Company and Atkins and O'Neil No. 3 J. F. Welder was drilled approximately one-half mile northeast of the No. 1 J. F. Welder. This well (No. 4 in Fig. 2) was abandoned as dry in July 1935. Early in 1936 the Humble Oil and Refining Company drilled their No. 1 J. F. Welder approximately one mile west of the original Atkins and O'Neil well. The Humble well (No. 5 in Fig. 2) was completed in April 1936, but it was also dry and abandoned.

Early Geophysical Exploration: During the period the Humble well was drilling, or immediately thereafter, a major oil company conducted a torsion balance survey west and southwest of well No. 1 in Fig. 2. Following this survey, a limited amount of seismograph work was done to the north of the well on behalf of the Wellington Oil Company. Using the results of this combination of surface work, subsurface information, torsion balance survey and seismograph profiling, a location was made for the Wellington Oil Company's (formerly Atkins and O'Neil) No. 1-B J. F. Welder (No. 6 in Fig. 2), located approximately two miles north of the original Welder test. Some shows were encountered in the Sinton sand, but the well was completed as dry and was abandoned in August 1937.

In October 1937, F. P. Schwab completed his No. 1 H. A. Smith just north of the present outline of Odem production. This well (No. 7 in Fig. 2), located three and one-half miles northeast of the first Welder well, encountered no production and was abandoned. The F. P. Schwab No. 1 S. L. Lane (No. 8 in Fig. 2) was completed in January 1938. The Lane well, slightly more than a mile to the west of the No. 1 H. A. Smith, encountered some gas but was finally classified as dry.

By the end of January 1938, the Odem area had received the eight exploratory tests for oil which are numbered 1 to 8 on Fig. 2 and fol-

lowing maps. There had been some encouraging shows of oil and gas, but no production of commercial value and all eight tests were listed as dry and were abandoned.

Later Geophysical Exploration: It was at this time that the Seaboard Oil Company of Delaware became interested in the Odem area. The high structural position of the area, as indicated by some of the wells drilled, and the encouraging shows of oil and gas obtained, caused Seaboard's Geological Department to recommend the area as favorable for additional exploration. In May 1938, therefore, a reflection seismograph survey was begun by shooting that part of the Welder Ranch around Angelita and the Atkins and O'Neil wells (Nos. 1, 2 and 4). This survey, employing the continuous profiling method, indicated approximately three hundred feet of southwest dip in this area. This dip was a component of reversal, and indicated a possible structurally high area to the north nearer the town of Odem.

The Odem area was almost completely under lease at the time of the survey, however, so the seismograph program was shifted to the area west and southwest of Angelita; an area extending into the northern part of Nueces County. This diversionary survey almost immediately discovered the Nueces County structure now designated as Riverside. This structure, shown on the seismograph map in Fig. 2, was later confirmed by the drilling that resulted in the discovery, by Seaboard, of an oil and gas field.

The faulting in the Riverside area, as shown by the seismograph map, as well as the axis of the structure, trended northeast toward the Odem area. This trend, together with the south dip previously established by the Angelita work, made the area adjacent to Odem an even more attractive prospect for exploration.

During the shooting of the Angelita and Riverside areas, enough leases had expired in the Odem area to warrant a geophysical exploration program there. Consequently, the continuous profiling survey being conducted was extended northward from Nueces County and the Riverside area toward Odem. As profiles were completed across the area, a structure with several hundred feet of closure became evident. The exploration program, completed in November 1938, depicted a northeast-southwest trending anticlinal structure just west of the town of Odem and between the No. 7 dry hole to the north and the No. 1 test in the Angelita area to the south. The final seismograph map of the Odem-Riverside trend is shown in Fig. 3.

It is worthy of comment, that during the entire "shooting pro-

gram," there was complete cooperation between R. P. Thompson, the party chief of the Geophysical Service Incorporated crew, and Sea-

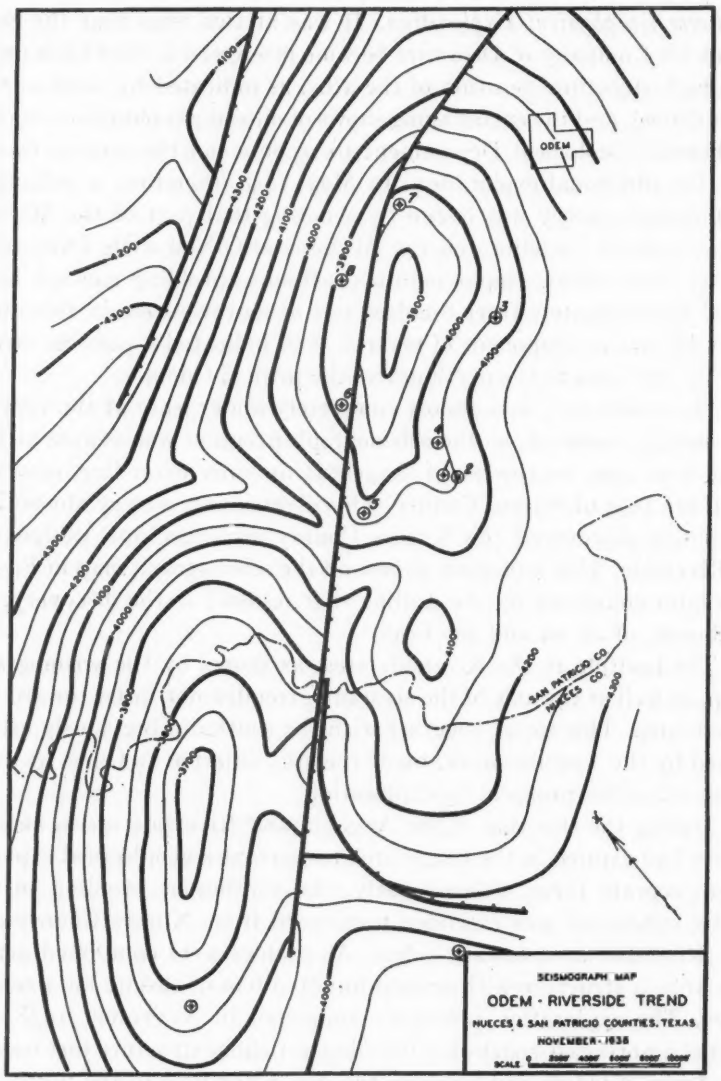

FIG. 3. Seismograph map of the Odem-Riverside area, November 1938, after the discovery of the Odem structure, showing the test wells drilled prior to the seismograph mapping.

board's Geological Department. All pertinent geological information of the Odem area possessed by Seaboard was in the hands of the party

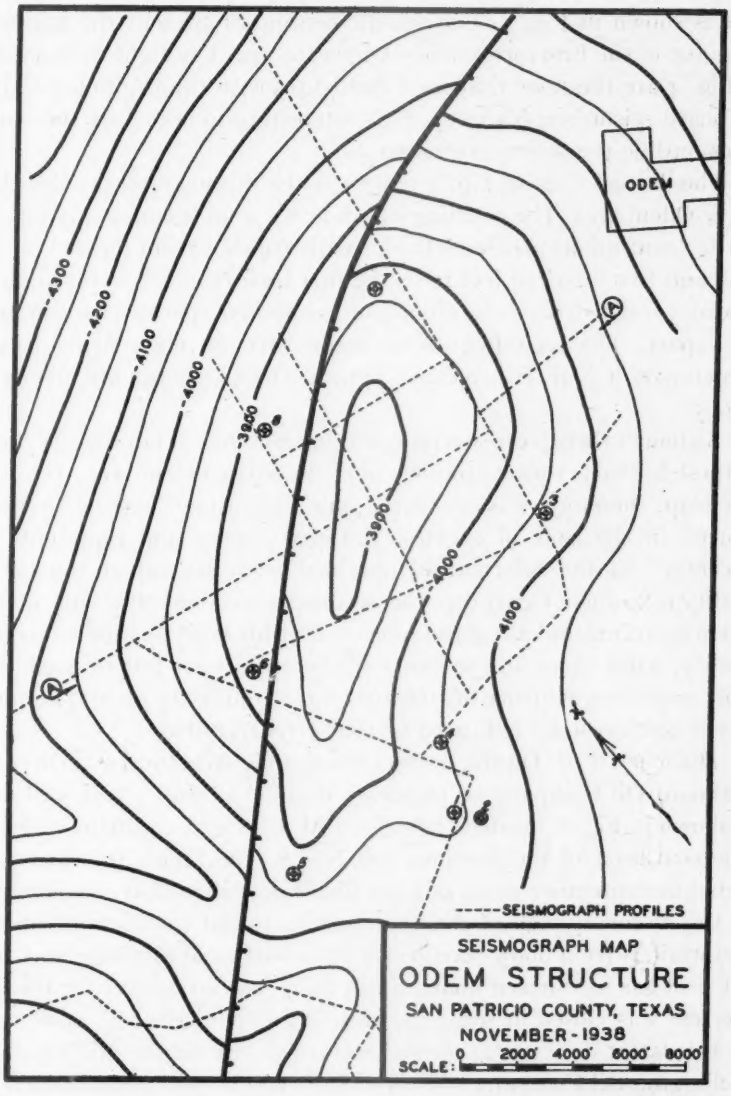

FIG. 4. Seismograph map of the Odem structure, contoured on the approximate top of the Frio formation. Seismograph profiles are shown as dashed lines. The circled wells were drilled before the start of the seismograph survey.

chief during the reflection survey, and weekly seismograph progress maps were furnished the goelogists.

The Odem Structure: The final seismograph map of the Odem structure is shown in Fig. 4. The seismic contours represent the approximate top of the Frio formation of Oligocene age. The eight wells shown in Fig. 4 are the tests that were drilled prior to the beginning of the Seaboard seismograph survey. It is interesting to note that these dry holes outline the seismic structure.

The dashed lines in Fig. 4 represent the seismograph profiles shot in the Odem area. The profiling was done by what is commonly known as the "continuous profile method," with the shot point located in line with and two hundred feet from the first instrument. The instrument spread consisted of eight groups of geophones spaced two hundred feet apart. The recordings were made with an eight-string galvonometer on a four inch record. Typical Odem records are shown in Fig. 5.

Although there were several reflecting horizons of fair quality, none of these horizons was continuous over the entire Odem area. The seismic map, therefore, was contoured on a "phantom" horizon that was plotted in the zone of greatest reflected energy and represents an "average" of the information obtained from several of the better quality reflectors. Generally, the seismograms along the axis of the Odem structure and along the zones of faulting were poor or no good in quality, while those on the flanks of the uplift were fair to good. The most promising evidence of structure was found in the several hundred feet of northwest dip indicated by the better records.

Discovery Well: On the basis of the seismic structural evidence, the Seaboard Oil Company of Delaware decided to drill a test well and, as shown in Fig. 6, located their No. 1 M. C. Smith approximately one mile southeast of the previous test No. 8. The Smith test was completed in September 1939, as a gas-distillate well, and is considered to be the discovery well of the Odem field. Initial production through perforations from 6995–7000 feet was 71 barrels of distillate and 2989 MCF of gas in thirteen hours. Since there was no market for the gas, the test was closed in from the date of completion until April 1941. At this latter date it was opened to furnish gas for the drilling of the Wellington Oil Company's No. 1-C J. F. Welder and furnished gas for drilling for about six months. It then began producing considerable amounts of salt water and after an unsuccessful work-over operation was abandoned in November 1941.

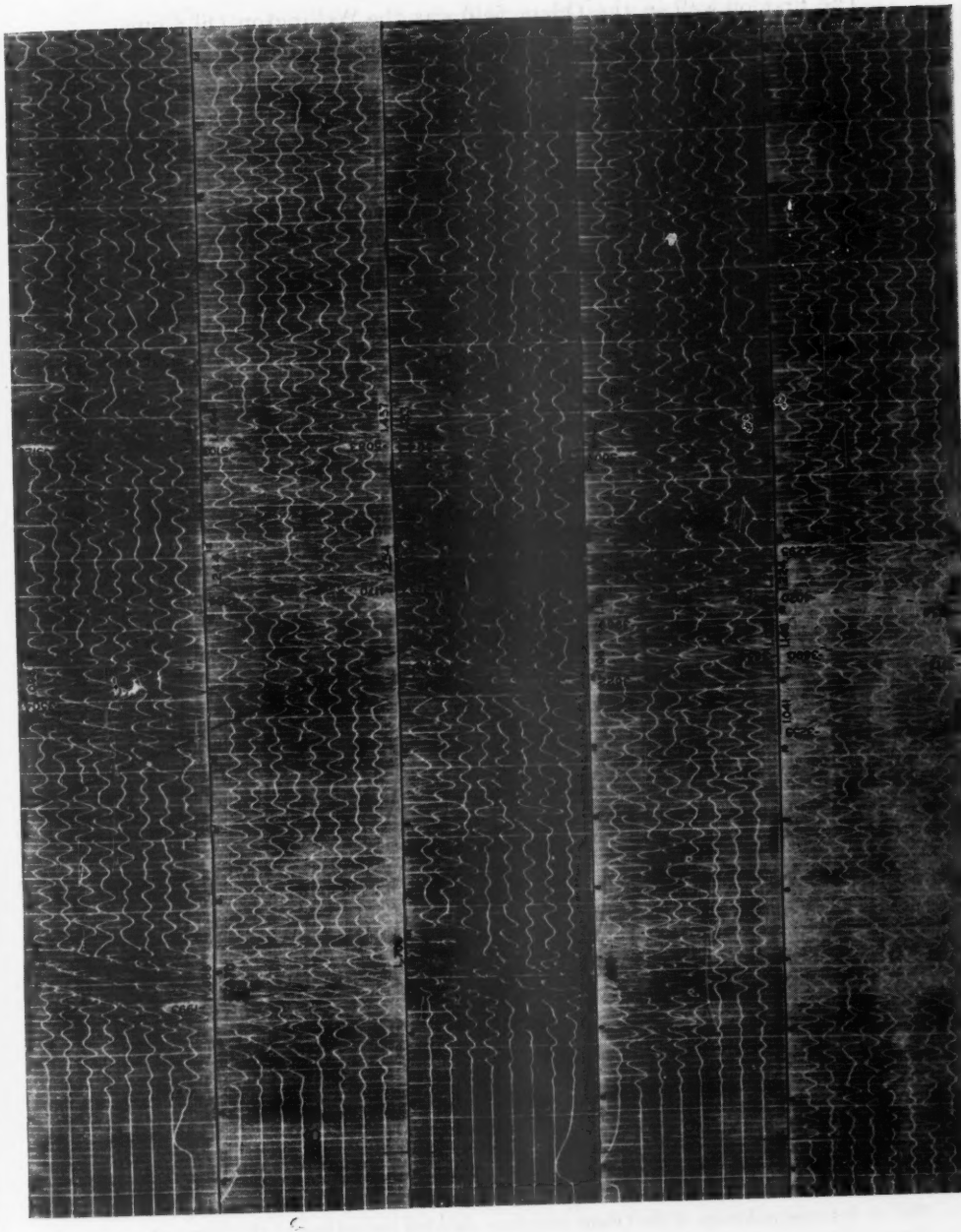

FIG. 5. Five seismograph records from adjacent spreads, showing the type of data obtained from the zone of faulting along the top of the Odem structure.

The first oil well in the Odem field was the Wellington Oil Company's No. 1-C J. F. Welder, located on the basis of the structural position of the No. 1 M. C. Smith and seismic information made

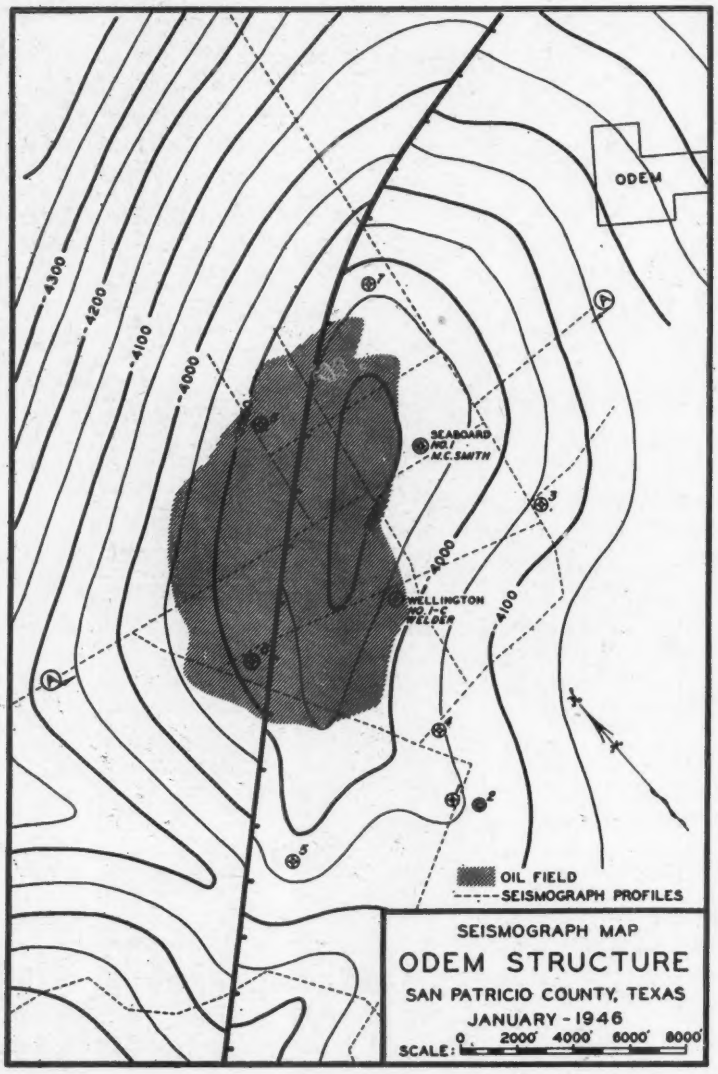

FIG. 6. Seismograph map of the Odem structure, showing the outline of the Odem oil field as of January 1946. Shown, also, is the location of the seismic cross-section A-A.

available to Wellington by Seaboard. It was completed in June 1941 through perforations from 5430–5434 feet with initial production of 157 barrels of oil per day through a ⅛ inch choke. After the completion of the No. 1-C Welder, drilling activity in the field was accelerated and at the present date, the field is almost completely drilled up.

It is interesting to note in Fig. 6 the positions of the Wellington Oil Company's No. 1-B J. F. Welder (old test No. 6) and the F. P. Schwab No. 1 S. L. Lane (old test No. 8) with relation to the Odem outline of production. Both of these wells, although completed as dry before the discovery of the field are located within the present limits of production. The Wellington test was cored and tested fifty feet below the top of the producing Sinton sand, and on a drill stem test made salt water. This well is now surrounded by producing wells and had it been properly tested would have been an oil well.

Test No. 8 did not produce because of unfavorable local sand conditions. The top of the Sinton sand in this well is very poorly developed and on a drill stem test it produced only a small amount of gas.

Comparison of Odem Seismic to Odem Subsurface Structure: The shaded area in Fig. 6 represents the Odem field as of January 1946. The comparison of seismic structure to present outline of production may be noted. Also shown is the location of the cross-section "A-A" that crosses the center of the field in an east west direction.

Figure 7 presents this east-west cross-section of the Odem field showing the relationship of the seismic profile "A-A" to the subsurface profile "A-A". The seismograph profile compares favorably with the subsurface profile in most aspects. The subsurface fault shown in Fig. 7 between wells No. 7 and No. 8 does not extend upward far enough to cut the seismic "phantom horizon" and consequently is not shown on the seismograph structure map. Conversely, the fault between wells No. 4 and No. 5 is indicated on the seismic horizon but dies out with depth and has little or no effect on the structure at the top of the Sinton sand.

A subsurface map of the Odem field contoured on the top of the Catahoula gas sand is shown in Fig. 8. At this level, which is only a few hundred feet above the seismic horizon, the structure, as indicated by drilling, checks closely the structure contoured on seismic data as shown in Fig. 6.

The actual subsurface on top of the deeper Sinton sand is illustrated in Fig. 9. This map reveals the additional faulting that develops

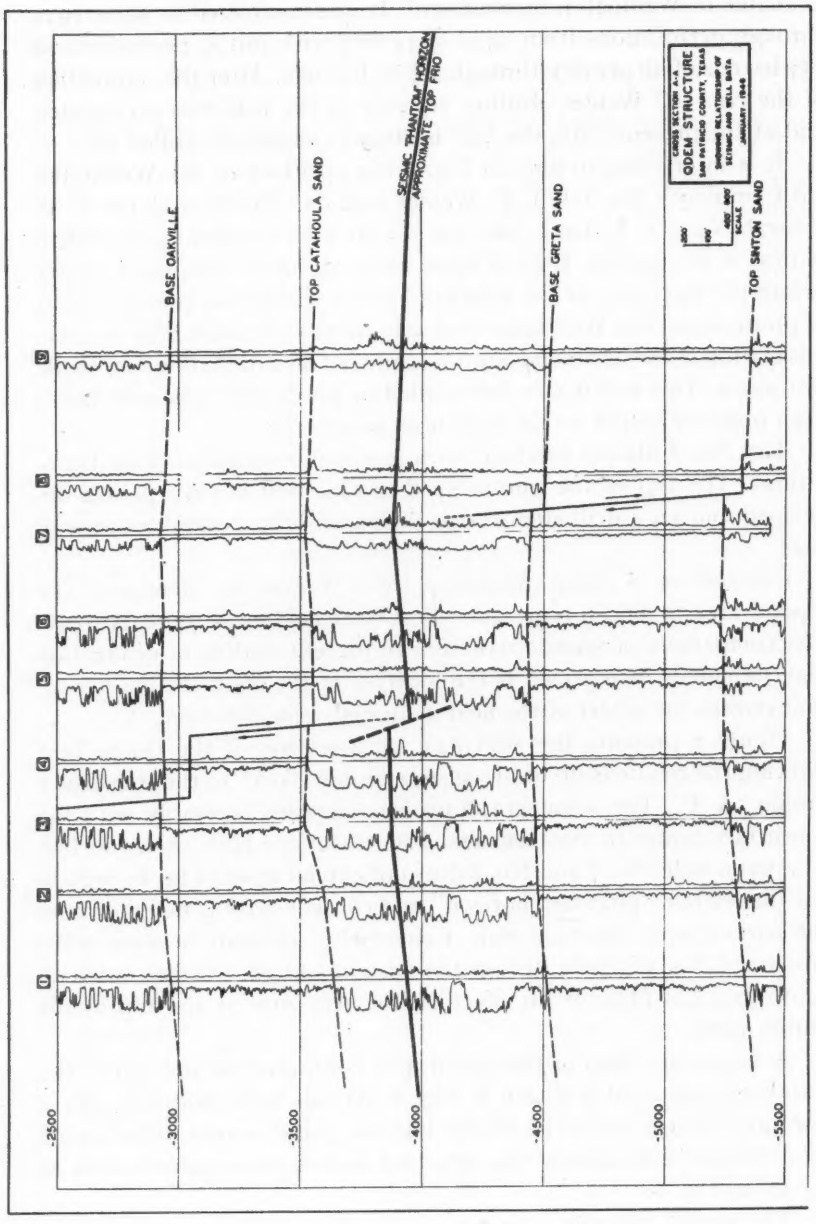

FIG. 7. The common seismograph and subsurface cross-section A-A across the Odem structure, comparing the seismic reflection horizon with the well data.

with depth. The lack of deep seismic information, which might have indicated this fault and the larger and more attractive upthrown area

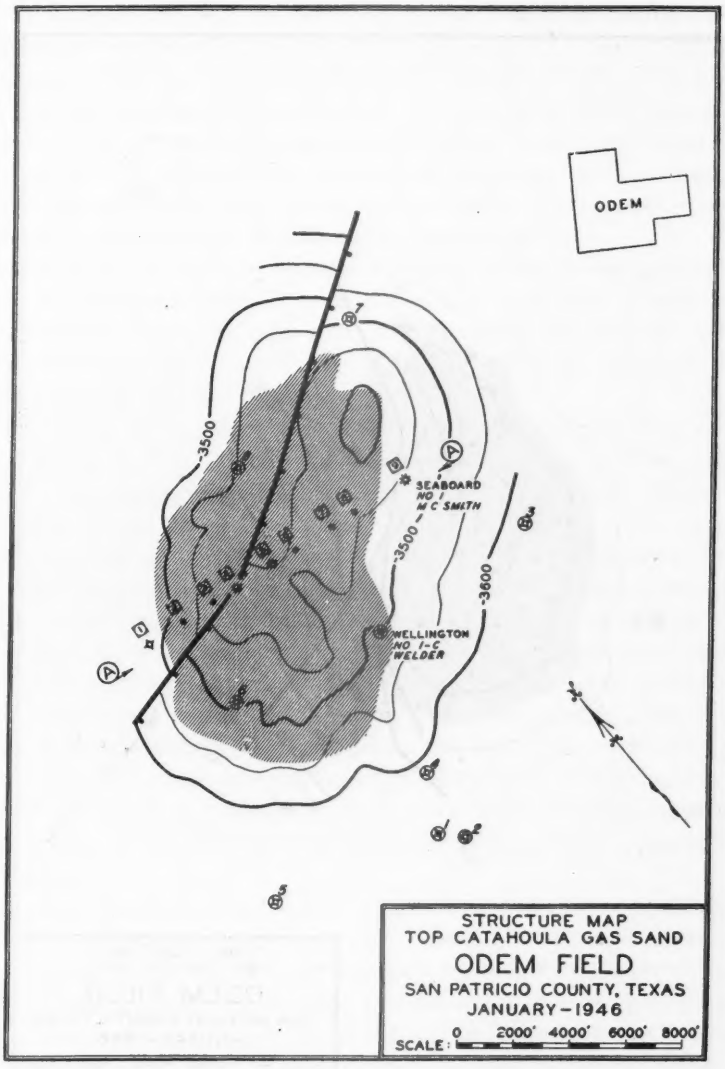

FIG. 8. Structure map of the Odem oil field contoured on the top of the Catahoula gas sand. The numbered wells shown are located on cross-section A-A, Fig. 7. The shaded area is the outline of production in the Sinton sand.

west of it, was responsible for the failure of the Seaboard Oil Company to discover the oil producing area of the Odem field with their first well, the No. 1 M. C. Smith.

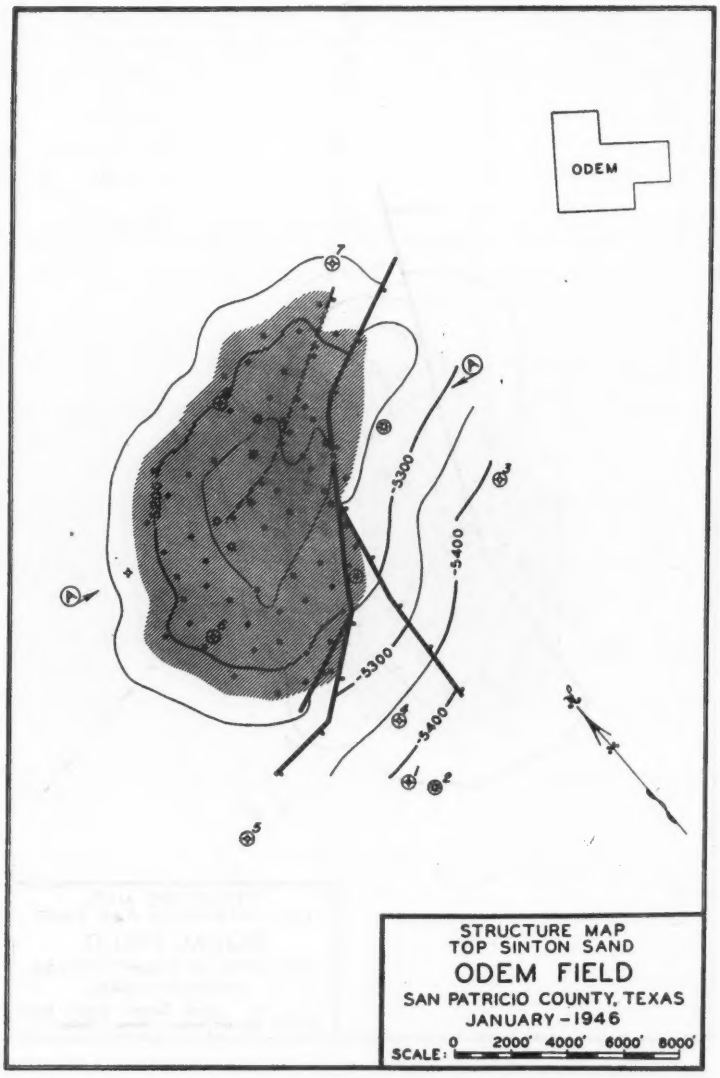

FIG. 9. Structure map contoured on the top of the Sinton sand. The productive Sinton sand area is shaded, and the field wells are shown by the conventional symbols.

Oil and Gas Sands: Development of the Odem field has revealed that there are eleven, and possibly twelve, sands on the Odem structure that carry gas or oil.

As indicated in Fig. 10, the first gas sand is encountered at approximately 2000 feet. This sand carried gas only and has a maximum thickness of thirty-two feet above water. The second sand is an eighteen-foot gas bearing sand at 2800 feet. The top of the Catahoula sand, at a depth of approximately 3500 feet, is the third productive horizon. This sand, with a maximum thickness of sixty-four feet, carries the largest gas reserve of any of the shallow sands. The 4400-foot sand also carries gas. It has a maximum thickness of fifty feet.

The Sinton sand group consists of a series of five oil and gas bearing sands encountered generally from a depth of 5300 feet to 5500 feet. These oil and gas sands, with an aggregate maximum thickness above water of one hundred and thirty-seven feet, comprise the main producing zone of the Odem field.

At approximately 6700 feet, 6800 feet and 6900 feet are encountered the three productive sands of the basal Frio group. These sands, with a maximum aggregate thickness of sixty feet, carry a considerable reserve of oil and gas.

Comparison of Seismic Closure to Productive Area: Figure 11 shows the relationship of seismic closure to proven production along the entire Odem-Riverside trend. It is extremely interesting to note that every closure on the seismograph map, with the exception of the low one-contour closure against a fault at the extreme north end of the area, is now productive. As indicated here, the seismic closures at Odem and East Riverside are oil fields, and the closures at Riverside proper and at O'Neil are gas fields. This very close relationship of seismic structure to productive area is certainly a most emphatic endorsement of the reflection seismograph as a method of petroleum exploration.

It might be of passing interest to note that several years after the discovery of the Odem field, several "bootleg" seismograph maps, purportedly of major company origin, were made available to Seaboard. These maps showed a large, favorable structure slightly northeast of the present center of Odem production, on which the Schwab dry holes appeared to have been drilled. It is fortunate for Seaboad that these maps were not in its possession at the time a seismic survey of the Odem area was contemplated, as it is doubtful that such a survey would have been made in the face of such unfavorable evidence.

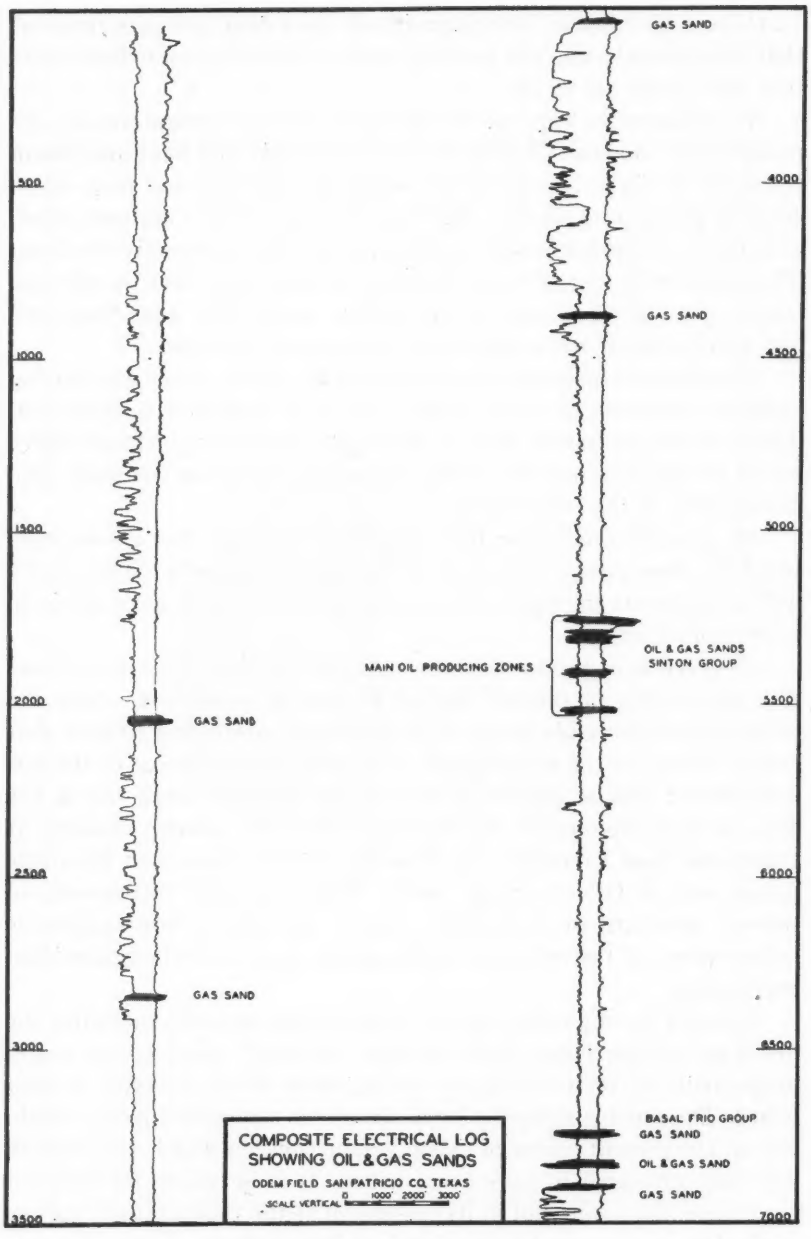

FIG. 10. Composite electrical log showing the oil and gas sands found in the Odem field.

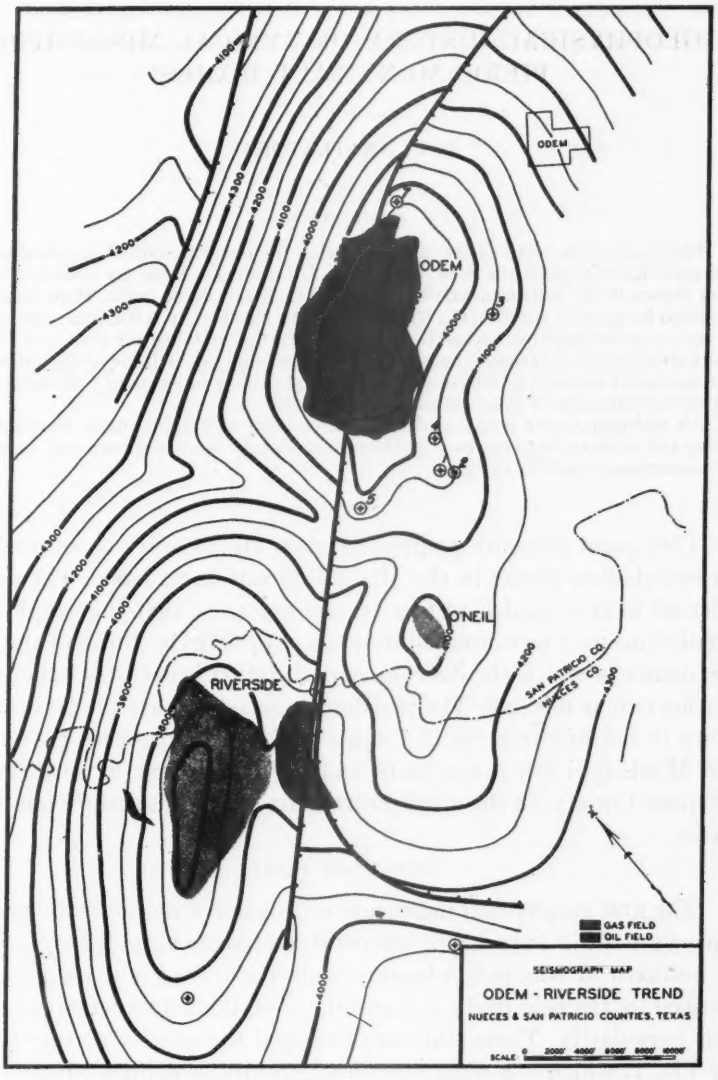

FIG. 11. Seismograph structure map of the Odem-Riverside area, showing the relationship of seismic closure to proven productive area.

Acknowledgments: The writers wish to thank Seaboard Oil Company of Delaware for permission to publish this paper; and Mr. R. A. Stehr and Mr. John M. Clayton for help and suggestions in the preparation of the paper.

GEOPHYSICAL HISTORY OF TYPICAL MISSISSIPPI PIERCEMENT SALT DOMES*

L. L. NETTLETON†

ABSTRACT

Maps and cross sections are given, showing the development of geophysical and geological knowledge of the New Home and D'Lo domes. Both are shallow, piercement domes in the northern part of the Mississippi salt dome basin. Both were first indicated by gravity surveys, the shallow cap-rock checked by refraction seismograph surveys, cap-rock depths checked by drilling and further seismograph work and drilling then carried out to determine the position of the salt and the attitude of the sediments. The successive items of geophysical work and test drilling have led to a consistent and orderly development of information about these domes.

An additional note is included, with three pairs of gravity maps, showing how strong and definite, but very local, gravity expressions of shallow domes may be missed by reconnaissance surveys.

This paper presents geophysical data and subsurface information on two shallow domes in the Mississippi salt dome basin. The domes selected have been drilled to a certain extent so that the geophysical predictions may be evaluated in terms of findings by the drill and also are domes in which the development situation is such that the information can be released. The two domes considered are the New Home dome in southeastern Smith County and in the northeasterly part of the Mississippi salt dome basin and the D'Lo dome in northcentral Simpson County, in the northcentral part of the Mississippi salt dome basin.

NEW HOME DOME

The first geophysical indication of this dome was given by gravity surveys made in 1937 during a general campaign of gravity exploration of southern Mississippi. A local irregularity in the gravity survey was noticed by the field party and additional stations were set out to check this irregularity. These stations developed the gravity picture shown by Fig. 1, which is a map of residual gravity remaining after the removal of a rather strong, northerly regional increase. It was quite certain from this picture that the area was underlain by a relatively shallow dome with a substantial thickness of cap rock. Further, the

* Read at the Chicago and Houston meetings of the Society, 1946.

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gravity pictures suggests that the salt column has a relatively small diameter because there is only a weak negative influence surrounding the gravitationally positive cap rock indication.

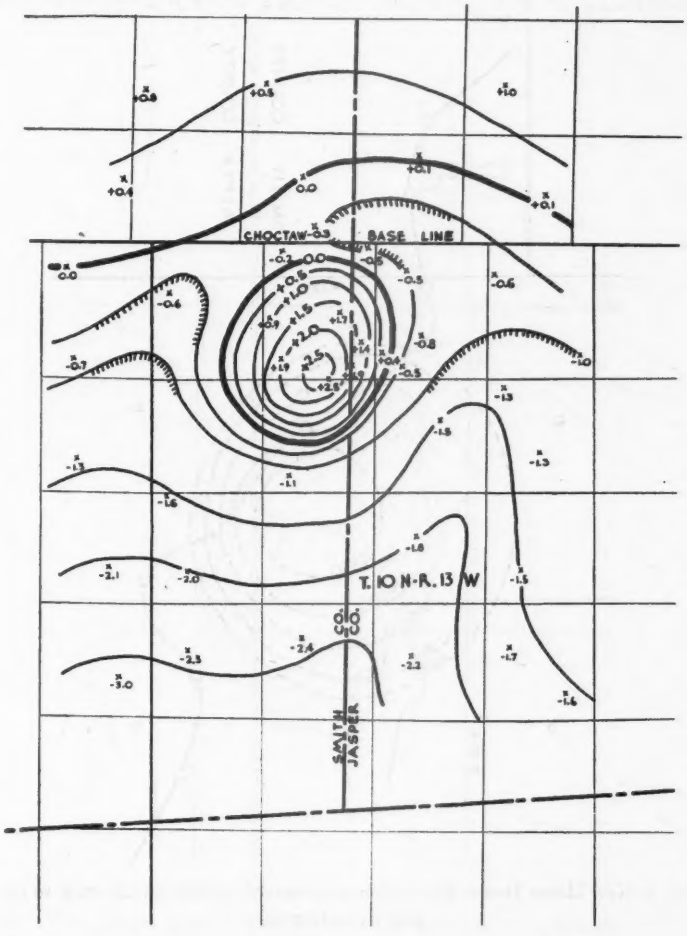

FIG. 1. New Home Dome. Residual gravity map. Contour interval 0.5 mg.

The next development was a small amount of refraction seismograph work early in 1940, which was done to check the approximate location and depth of the cap rock indicated by the gravity survey. This gave the results shown by Fig. 2 and confirmed the existence of

shallow cap rock with its general form and position in close agreement with the gravity predictions.

The findings of the refraction seismograph work have since been substantially confirmed by drilling, the results of which are indicated

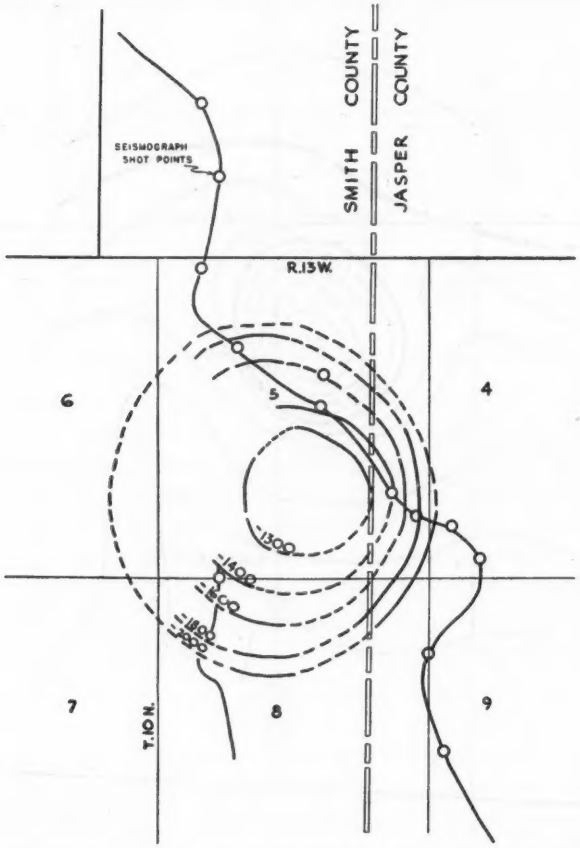

FIG. 2. New Home Dome. Refraction seismograph survey on cap rock to check gravity indications.

by Fig. 3, which shows contours on top of the cap rock, controlled by six tests. These show the dome to be slightly elliptical in shape with the cap rock depths a little less than were calculated from the refraction seismograph work.

At this stage, a serious attempt to develop the oil prospects of the dome was started. The Gulf No. 1 King was drilled some 1,500 feet

south of the Foley test (at the south edge of the cap rock area) and encountered no dome material. The situation at this stage is shown by Fig. 4, which shows (1) the cap rock surface as derived from the refraction seismograph work (from the contours of Fig. 2), (2) the actual

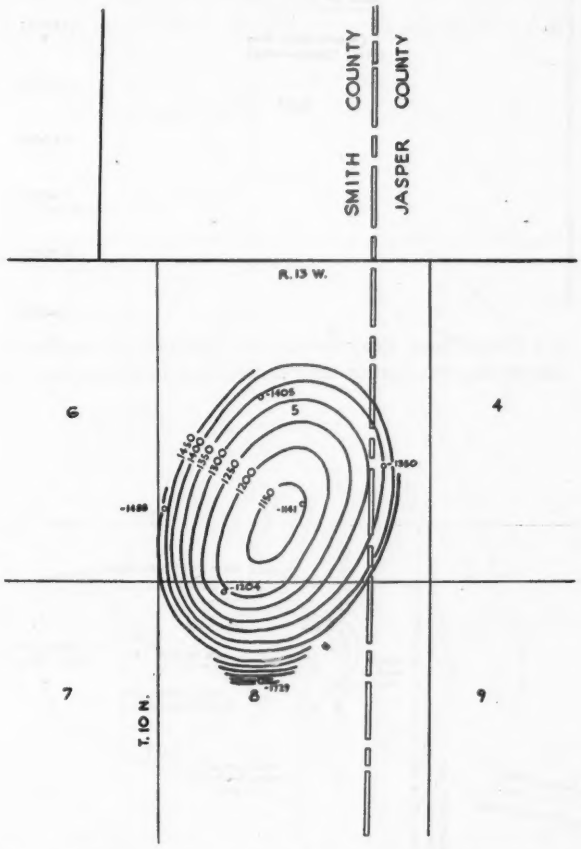

FIG. 3. New Home Dome. Contours on cap rock from drilling.

cap rock surface from drilling as taken from the contours of Fig. 3, (3) the base of the cap rock as estimated from the thickness required to account for the magnitude of the positive gravity anomaly, and (4) the position of the King test.

With the geophysical and geological information represented by Fig. 4, there was still no very good basis for estimating the distance

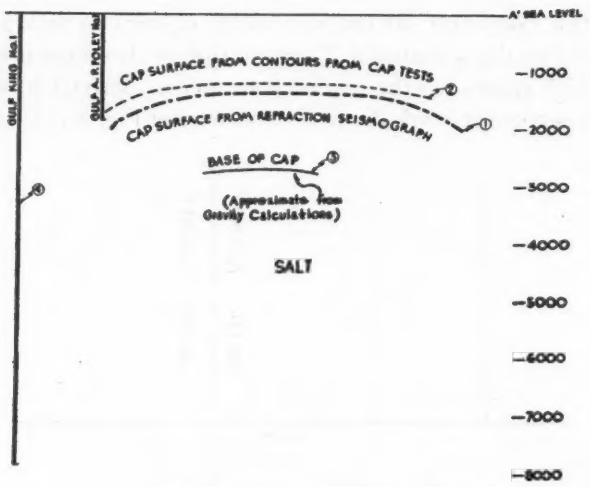

FIG. 4. New Home Dome. Cross section, showing status of geophysical and sub-surface information after drilling first deep flank test.

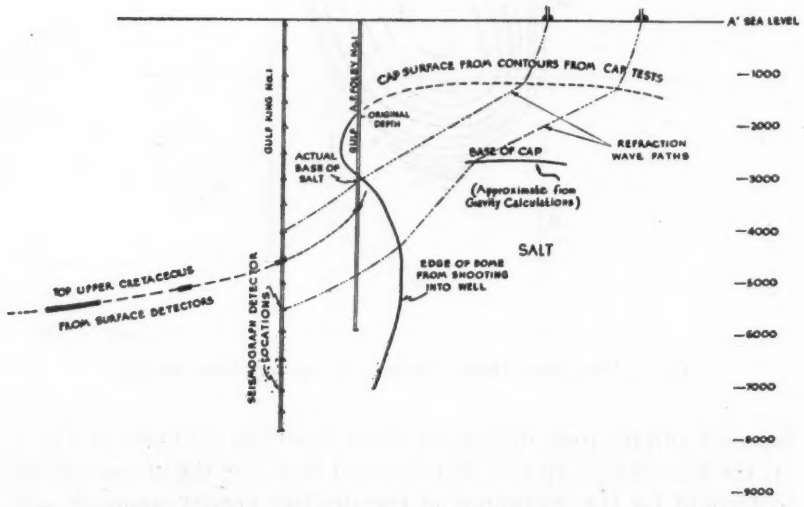

FIG. 5. New Home Dome. Cross section showing refraction survey to detectors in the first deep test (Gulf King No. 1), the edge of the salt as derived from this survey, showing overhang of the south flank of the dome and the subsequently deepened A. P. Foley No. 1 test.

from the deep King test to the salt column, and whether or not there was sufficient room for production prospects between that test and the dome. To answer this question, it was decided to make a refraction seismograph survey into detectors in the King test together with some refraction work to surface detectors.

The detector positions in the well are shown in Fig. 5. Sample shot

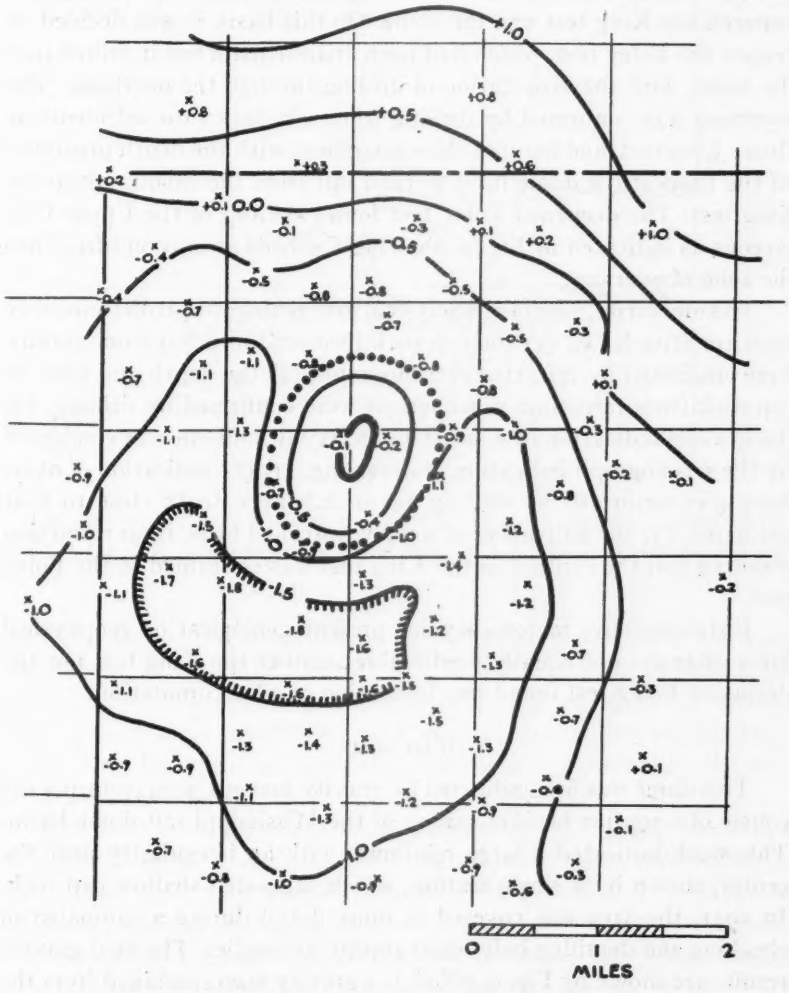

FIG. 6. D'Lo Dome. Residual gravity map. Contour interval 0.5 mg. Edge of dome, as derived from this survey shown by heavy dotted line.

points and refraction wave paths are also shown. This shooting into the well indicated the side of the dome toward the King test to have a well developed overhang. Furthermore, the refraction shooting to surface detectors had given some control on the top of the Upper Cretaceous, as indicated at the left side of Fig. 5. This dip away from the dome together with the indication that the King test was around 2,000 feet away from the salt indicated possible chances for production between the King test and the dome. On this basis, it was decided to deepen the Foley test, which had been abandoned when it drilled into the dome, with the expectation of drilling through the overhang. The overhang was confirmed by drilling from salt back into sediments at about 3,000 feet, and in quite close agreement with the depth predicted on the basis of the dome form worked out from the shooting into the King test. The deepened Foley test found the top of the Upper Cretaceous as indicated in Fig. 4, showing the beds steeply uplifted into the zone of overhang.

To summarize, several geophysical and geological predictions have been confirmed, i.e., (1) the cap rock form and location from gravity were confirmed by refraction seismograph, (2) the depth and form of cap rock from refraction seismograph were confirmed by drilling, (3) the gravity indication of a small diameter salt column was confirmed by the seismograph indication of overhang, (4) the indication of overhang was confirmed by drilling out of salt at a depth close to that predicted, (5) the indication of steeply upturned beds, from refraction shooting and the contact in the King test was confirmed in the Foley test.

Unfortunately, factors beyond present geological or geophysical knowledge are not equally predictable; neither the King test nor the deepened Foley test found any indication of oil accumulation.

D'LO DOME

This dome was first indicated by gravity surveys in 1937 during the course of a routine blanket survey of the Mississippi salt dome basin. This work indicated a large minimum with an irregularity near the center, shown by a single station, which suggested shallow cap rock. In 1941, the area was covered in more detail during a campaign of checking and detailing individual gravity anomalies. The final gravity results are shown by Fig. 6, which is a gravity map combined from the stations of both surveys after the removal of a strong southeasterly

regional. On the basis of this survey, an approximate edge of the cap rock was estimated, as is indicated by the heavy dotted line.

Next, the dome was checked by two traverses of refraction seismograph work in July, 1941, as shown by Fig. 7. The contours on the cap rock as derived from this work are in very close agreement with the

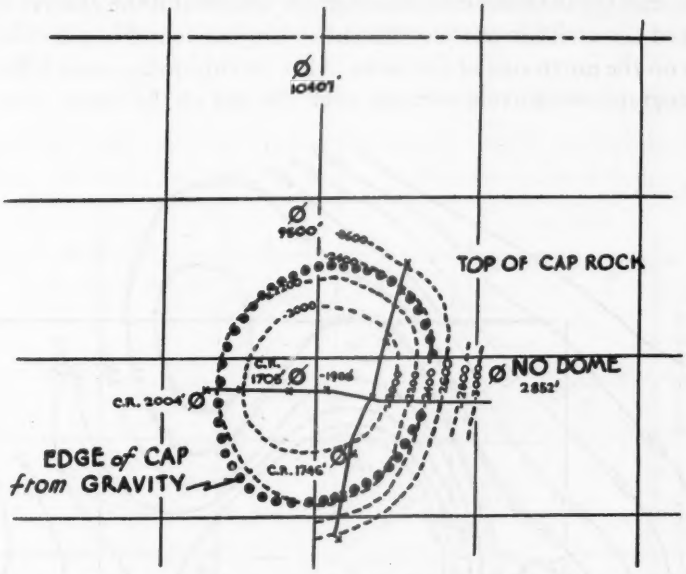

FIG. 7. D'Lo Dome. Refraction seismograph survey to check gravity survey. Tests to cap rock, giving depths to top of cap shown, were drilled after seismograph survey.

position of the dome as estimated from the gravity surveys. The map also shows the depths of the cap rock as found in three subsequently drilled tests. The general form of the cap rock as indicated by this drilling is in substantial agreement with the refraction seismograph predictions, but the depths are about 200 feet shallower than the seismograph indications.

A reflection seismograph survey made in 1943 gave the results shown by Fig. 8. This indicates a sedimentary uplift quite close in around the dome with a nearly complete rim syncline. This situation has been generally confirmed by the two deep tests drilled on the north side of the dome which have found dips between them substantially in accord with the reflection seismograph predictions.

The general situation is summarized by the section, Fig. 9, which shows (1) the residual gravity profile, (2) an estimate of the isolated positive gravity anomaly due to the cap rock, (3) the top of the cap rock by the refraction seismograph, (4) the bottom of the cap rock based on the thickness calculated from the isolated positive gravity effect, and (5) the reflection seismograph results and the general agreement of the attitude of the sediments with that found in the two deep wells on the north side of the dome. Also, on this dome, some reflection seismograph work from spreads over the top of the dome gave late

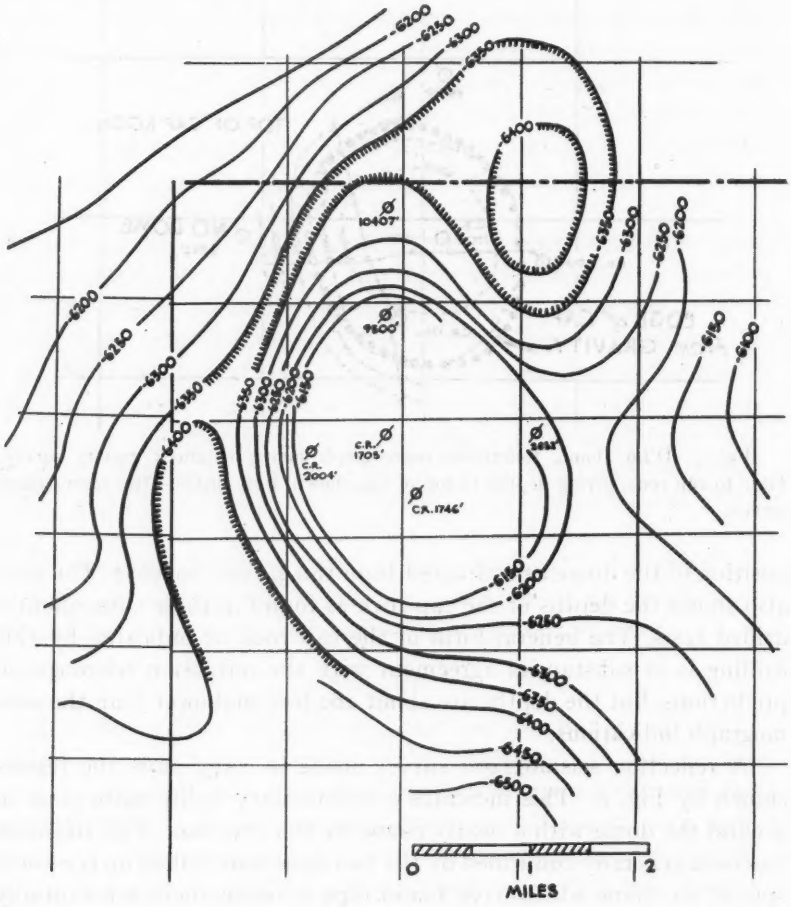

FIG. 8. D'Lo Dome. Reflection seismograph survey, showing almost complete rim syncline.

arrivals which were interpreted as reflections from the base of the salt and indicate that the salt column extends downward to a depth of approximately 25,000 feet. On the basis of this depth and the magnitude and form of the negative gravity effect, the approximate diameter of the required salt column was estimated. This gives the position of the salt flank, (6) as shown by the dashed vertical lines.

GRAVITY EXPLORATION FOR SHALLOW DOMES

The final section of this paper has been prepared to show how the presence of small, shallow domes in the Mississippi salt dome basin

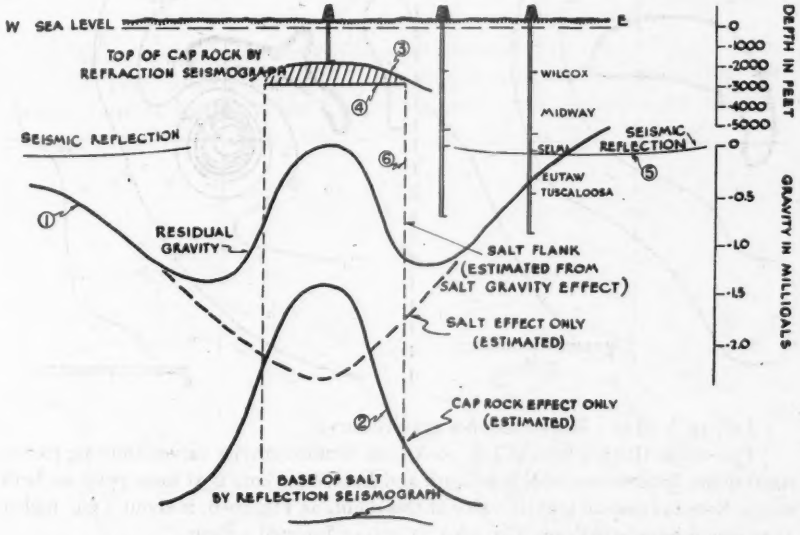

FIG. 9. D'Lo Dome. Cross section summarizing results of geophysical surveys.

can be completely missed or not recognized in reconnaisssnce gravity surveys although very definite anomalies are actually present. This situation arises from the fact that a number of domes must have quite shallow cap rock but are without a substantial salt mass, so that the gravity effect consists of a small, circular gravity high without any surrounding minimum. In spite of the fact that the gravity effect may be 2 mg. or more, some of the anomalies cover such small areas that the total gravity expression may be contained in an area of only about one square mile. When reconnaissance surveys are made along roads and trails, such anomalies may be missed entirely or may be indicated

only by a single station which appears to be erratic, and may be considered to be in error.

The pairs of maps shown by Figs. 10, 11, and 12 have been selected to illustrate this point. In each case, the area had been covered by a reconnaissance survey and later was filled in with considerable detail. All the features shown are from shallow dome indications, not yet tested by drilling so the locations cannot be disclosed, other than to state that all are within the Mississippi salt dome basin and in between certain of the known domes of that area.

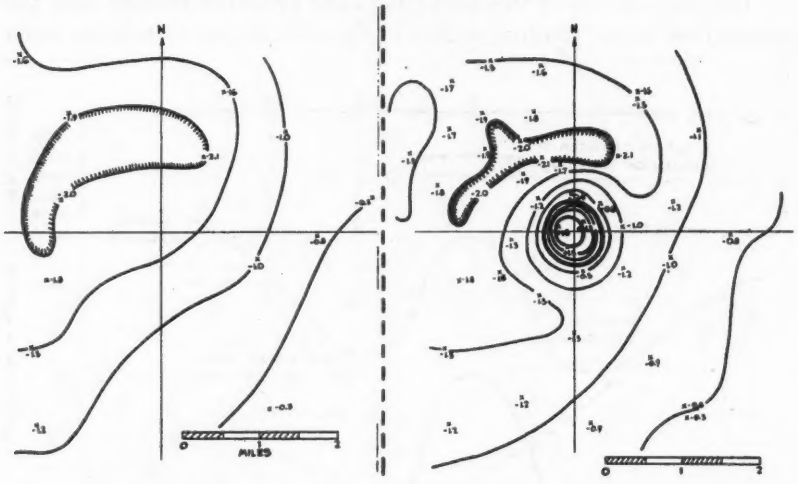

FIG. 10-A. (Left) Reconnaissance gravity survey.

FIG. 10-B. (Right) Area of Fig. 10-A after detailed gravity survey showing piercement dome. Intersection of North-South and East-West lines is at same point on both maps. Note that actual gravity value at this point, on Fig. 10-B, is about 3 mg. higher than would be inferred from Fig. 10-A. (Contour Interval 0.5 mg.)

Fig. 10-A is a residual gravity map from a rather open reconnaissance net of stations, at a spacing of about one mile along the roads. There is little suggestion of the presence of a shallow dome, except possibly the crescent shape of the low closing contour. Fig. 10-B shows the same area, including all the stations of Fig. 10-A together with those made in detailing the area. The North-South and East-West lines on the two figures are at the same location on the two maps, with their intersection near the center of the gravity anomaly. There is little suggestion in Fig. 10-A that the gravity value at this intersection is actually over 3 mg. higher than would be expected from that map.

Figs. 11-A and 11-B are a similar "before and after" pair. Here

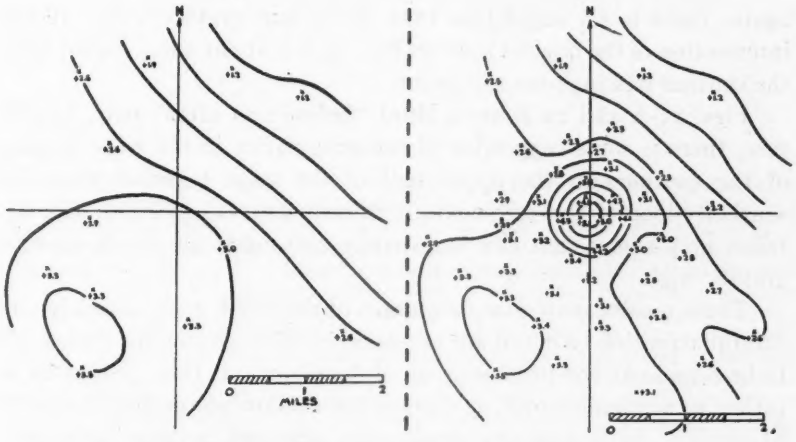

FIG. 11-A. (Left) Reconnaissance gravity survey.

FIG. 11-B. (Right) Area of Fig. 11-A after detailed gravity survey. Note that at point of intersection of crossed lines, the gravity value is about 2 mg. higher than would be inferred from Fig. 11-A. (Contour Interval, 0.5 mg.)

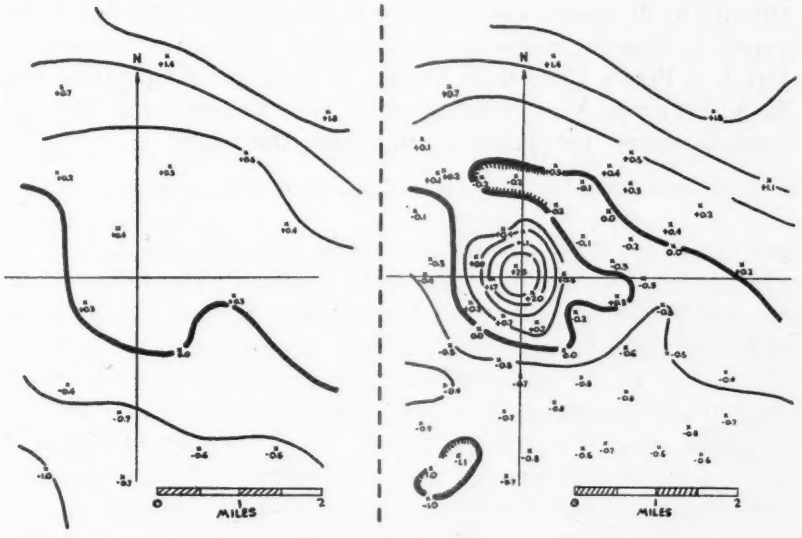

FIG. 12-A. (Left) Reconnaissance gravity survey.

FIG. 12-B. (Right) Area of Fig. 12-A after detailed gravity survey. Note that there is some suggestion of irregularity in Fig. 12-A, but that at point of intersection of crossed lines the gravity value is about 2 mg. higher than would be inferred from Fig. 12-A.

again, there is no suggestion that the actual gravity value at the intersection of the crossed lines on Fig. 10-A is about 2 mg. higher than the contour passing near this point.

Figs. 12-A and 12-B are a third "before and after" pair. In this case, there is some suggestion of the irregularity in the wide spacing of the contours in the upper half of the map, together with the southerly loop of the zero contour (shown by a heavy line). The detailed map shows that this loop partly surrounds the small, circular gravity high.

These results show that, in an area of this kind, good coverage and careful attention to detail are necessary, if all such shallow domes are to be found. At the present stage of development, this appears to be rather an academic point, as none of the shallow piercement domes of Mississippi have had any production although several have been drilled to a limited extent.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to many colleagues of the Gulf Research and Development Company who have contributed by discussion and otherwise to the material contained in this paper; to Robert Craighead, who prepared the illustrations; and to Drs. L. J. Peters, Chief of the Division of Geophysical Operations and E. A. Eckhardt, Vice-President of the Gulf Research and Development Company, for permission to publish this paper.

AMBIGUITY IN GRAVITY INTERPRETATION

D. C. SKEELS

ABSTRACT

It is shown that contrary to what is stated and implied in much of the literature, gravity data cannot, of themselves, be interpreted uniquely. It is shown by means of a two-dimensional example that for a given anomaly and a given density contrast a wide range of possible interpretations can be made, at various depths, and that whereas there is a maximum depth for the solution the minimum depth is zero. Other examples are given to show that depth rules based upon the assumption of geometrical shapes may give results very much in error when applied to actual anomalies. Nor does the method of interpretation by vertical gradients allow us to make an unique interpretation, or to distinguish deep from shallow anomalies as has been claimed. It is shown that we do not escape the ambiguity by using second derivative quantities such as gradient and curvature, and that, in fact, gravity and its derivatives are related by a corollary of Green's theorem. This theorem provides an analytical proof of ambiguity not only for the case of gravity data but for magnetic data as well.

An outstanding development of recent years has been the great increase in the use of the gravitational method of prospecting, resulting from the replacement of the slower and more cumbersome torsion balance by the gravity meter. It has frequently been lamented, however, that while the number of gravity data has increased by leaps and bounds, there has been no comparable improvement in the art of gravity interpretation. What is usually implied in these lamentations is that the interpreter should endeavor, by some means or other, to translate the gravity data into structure contours, or something resembling structure contours, analogous to the reflection time maps of the seismographer.

This attitude reveals a failure to appreciate the fundamental limitation of the gravitational method, a limitation which it shares with the magnetic method, namely, that the gravitational field is not in itself sufficient to define the mass distribution which produces it. This was stated very clearly by Nettleton,[1] who says:

"The interpretation of a gravity (or torsion balance) map in terms of a definite mass distribution below the surface is never unique on the basis of gravity information alone. This results from the fact that a given gravity distribution can be produced by a variety of mass distributions. Therefore, any mass distribution or geologic condition that is given as a solution for the cause of a given gravity distribution *depends upon additional control other than gravity.* This lack of unique-

[1] L. L. Nettleton, *Geophysical Prospecting for Oil* (McGraw-Hill, 1940) pp. 101–102.

ness of the solution for the cause of a given gravity picture cannot be emphasized too strongly."

In spite of this statement, there are still those who claim to have discovered methods which lead to unique solutions, and there are many others who feel that some such method could be found if sufficient thought were given to the problem. There is abundant evidence that the fundamental ambiguity of gravity and magnetic data is still not widely known or appreciated. Most of the literature on gravimetric prospecting does not mention ambiguity, and many papers which have been published imply, if they do not actually say, that gravity data can be interpreted uniquely. It would therefore seem to be in order to amplify Nettleton's remarks somewhat and to point out some of the limitations which ambiguity imposes upon gravity interpretation.

It can be demonstrated easily that the gravity data alone are not sufficient to define the mass distribution, by referring to a two-dimensional example. In Fig. 1 assume that we have observations of gravity at each of the seventeen stations indicated on the profile, and that these observations are correct to within one-tenth of a milligal. We assume that the gravitational field is truly two-dimensional, which is to say that the gravity contours are parallel straight lines, so that all profiles drawn normal to them are identical with this one. We also assume that the observations have been completely corrected for latitude and regional effects. Let us also assume that we know from experience in adjacent areas that the gravity variations are due entirely to relief or structure on the surface of a basement of uniform density of say 2.6, which is overlain by an unknown thickness of sediments of uniform density 2.4. We have then a two-dimensional problem with a single horizon of density contrast. From its simplicity this would seem to present a favorable case for quantitative interpretation. The question is, can we find, from the gravity data, the depth to the basement surface and the configuration of that surface?

The usual method of attacking this problem is by the use of graticules or other integrating devices, and a process of trial and error. We assume a configuration at some depth, and calculate by means of the graticule the gravitational effect of the assumed structure at the various stations; comparison of the calculated with the observed profile indicates where we must change our assumed configuration to get a better fit; we draw the new configuration, calculate, compare, and so on until we obtain a structure whose calculated effects differ from the observed effect by less than the observational error.

The structure numbered 1 in Fig. 1 was obtained in this way. It was assumed in calculating this configuration that the basement flattened out off the structure to a depth of 1000 meters. The configura-

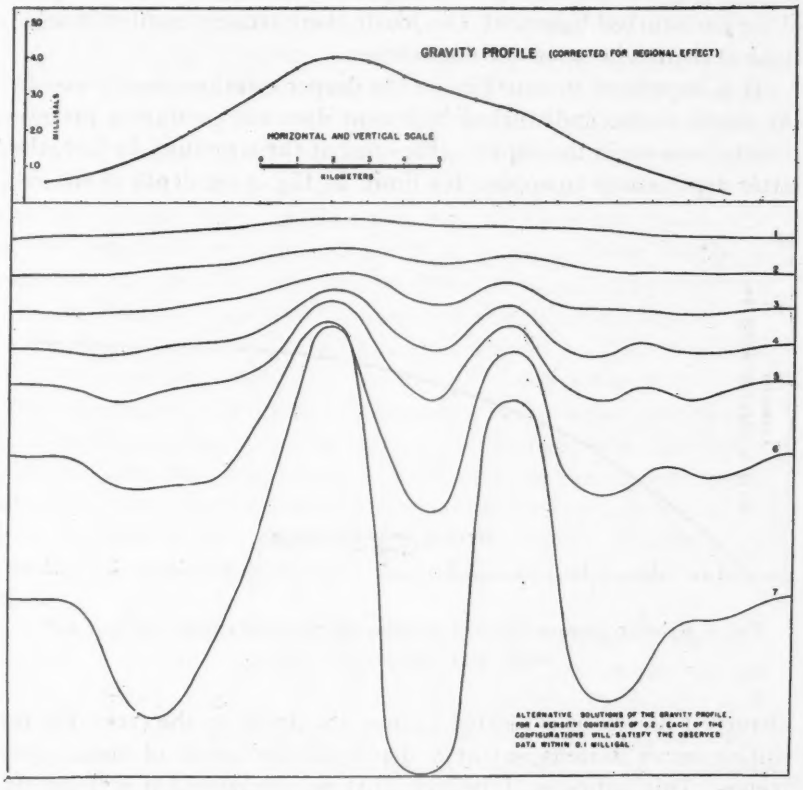
GRAVITY PROFILE (CORRECTED FOR REGIONAL EFFECT)
HORIZONTAL AND VERTICAL SCALE
KILOMETERS
ALTERNATIVE SOLUTIONS OF THE GRAVITY PROFILE. FOR A DENSITY CONTRAST OF 0.2 . EACH OF THE CONFIGURATIONS WILL SATISFY THE OBSERVED DATA WITHIN 0.1 MILLIGAL

FIG. 1. Various solutions of a basement profile to satisfy the gravity profile shown. The several solutions are all calculated for a density contrast of 0.2, but for various assumed depths of the undisturbed surface. All solutions satisfy the gravity profile within 0.1 milligal or less.

tion shown satisfies the observed data to within 0.1 milligal. It may, be regarded, therefore, as a possible solution.

Now if we lower this whole structure until the undisturbed basement has a depth of 2000 meters, and calculate its gravitational effect, we find that it no longer satisfies the observed anomaly; but by altering the shape, increasing the height here and decreasing it there, we

arrive at a second figure which also satisfies the observed data within 0.1 milligal. Similarly, we lower this structure another 1000 meters, and after some trial and error we find a third structure, and so on; seven configurations are shown in all, corresponding to different depths of the undisturbed basement. Obviously there are any number of solutions at depths between the ones chosen.

It is important to note that in the deeper solutions an increase in the depth to the undisturbed basement does not produce a proportionate increase in the depth to the crest of the structure. In fact, the latter depth seems to approach a limit. In Fig. 2 the depth of the un-

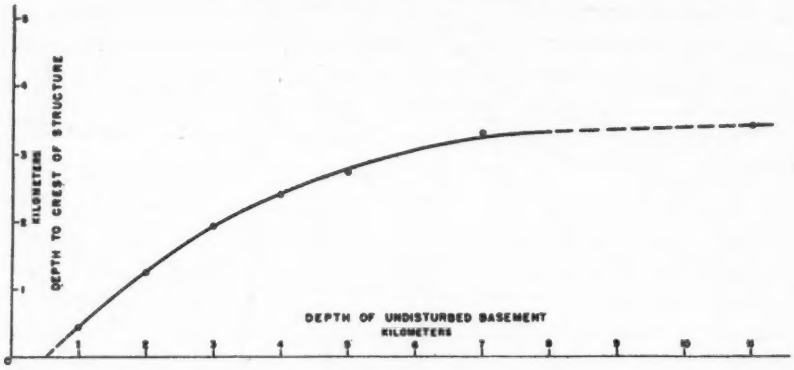

FIG. 2. Relation between depth of undisturbed basement surface of Fig. 1 and depth to crest of the disturbance.

disturbed basement is plotted against the depth to the crest; the resulting curve flattens out at a depth (of the crest) of about 3500 meters. This indicates, I believe, that no configuration will satisfy the data if the depth to the crest is more than 3500 meters. Thus, although the gravity data cannot tell us how deep the structure is which causes the anomaly, they do limit the depth to the top of the structure, (for a given density contrast) and this "limiting depth" may be very useful information.

There is, however, no shallowest limit except that provided by the surface of the ground. Were it not for the limitations of our graticule, we could have derived a structure whose crest was tangent to the surface; and extrapolation of the left-hand side of the curve of Fig. 2 shows that the depth to the undisturbed basement for this solution

would be about 500 meters. That is, this shallowest structure would have a relief of 500 meters, and this is the lowest relief that any structure can have and still satisfy the anomaly for the density contrast assumed. This concept of "lowest relief" is of considerable value in practical interpretation.

Aside from the "limiting depth" and the "lowest relief," however, the data themselves tell us little that is definite about the structure which causes the anomaly. If, by some independent means we could determine the depth to the surface of density contrast at some point, (assumed in this case to be the basement) we could then derive the structure for that depth, or if in some way we knew how much relief the structure had and its density contrast, we could choose the appropriate solution and thereby fix the depth. A unique interpretation, therefore, depends upon some information other than gravity.

We should point out that in actual practice it is often possible to limit the range of possibilities considerably even without any very definite geological information. Some of our deeper solutions are very improbable geologically, and in many areas the basement is known to be deeper than some figure, which would rule out the shallower solutions, (if it were certain that the anomaly were due to relief on the basement surface). Even after elimination of these improbable cases, however, there usually remains a considerable range of possible solutions.

It should be remembered that the case just presented was purposely idealized. It is not often in nature that we can assume a single surface of density contrast. The sediments usually show density variations, and in most cases the density increases with stratigraphic depth, so that there are several surfaces of density contrast. If the sediments are folded, each of these surfaces contributes to the anomaly. The basement is rarely homogeneous in density; the igneous and metamorphic rocks of which it is composed may range in density from 2.6 to 4.0 or more, and masses of abnormal density within the basement may give rise to anomalies which are indistinguishable from those due to basement relief.

For example, Fig. 3 shows an alternative interpretation of our anomaly of Fig. 1, in which it is assumed that the greater part of the anomaly is due to a basic intrusion entirely within the basement, with a small residual anomaly caused by structural relief on the surface of the limestone at a relatively shallow depth. Obviously it would be

impossible to tell from the composite anomaly how much if any was to be attributed to intrabasement effects and how much to structure.

The "trial-and-error" method used in the calculations for Fig. 1 is fairly standard practice, and is sometimes referred to as the "indirect method." Proposals have been made from time to time to shorten the interpretation process by using methods which give an answer

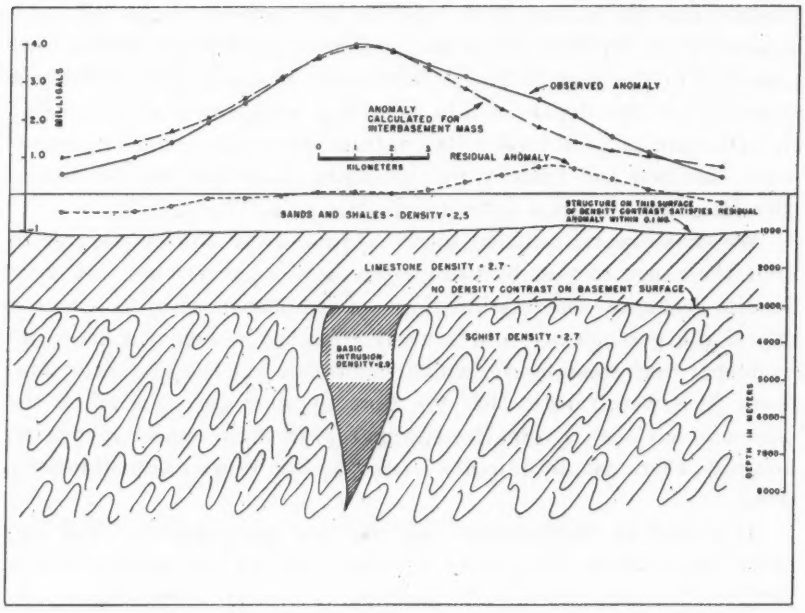

FIG. 3. Alternative interpretation for same gravity curve as in Fig. 1, assuming a combination of intrabasement and sedimentary effects to explain the anomaly.

directly. It is clear from what we have just seen that if any such method gives only one solution, without the use of some data other than gravity, it must be either an illusion or there must be some assumption involved which has to be fulfilled before the method can be applied.

One such method which is frequently used consists in the comparison of the observed anomaly profile with profiles calculated for masses of certain regular geometrical shapes, at various depths. Coincidence between the observed profile and one of these calculated profiles does

not, however, assure us that the disturbing mass actually has the shape of the assumed mass. Fig. 4 shows the gravity profile calculated for a vertical step-fault, which is shaded in the lower part of the figure. But identical effects will be caused by the flexure shown at a shallower depth, and, in fact, by a whole family of flexures at various depths.

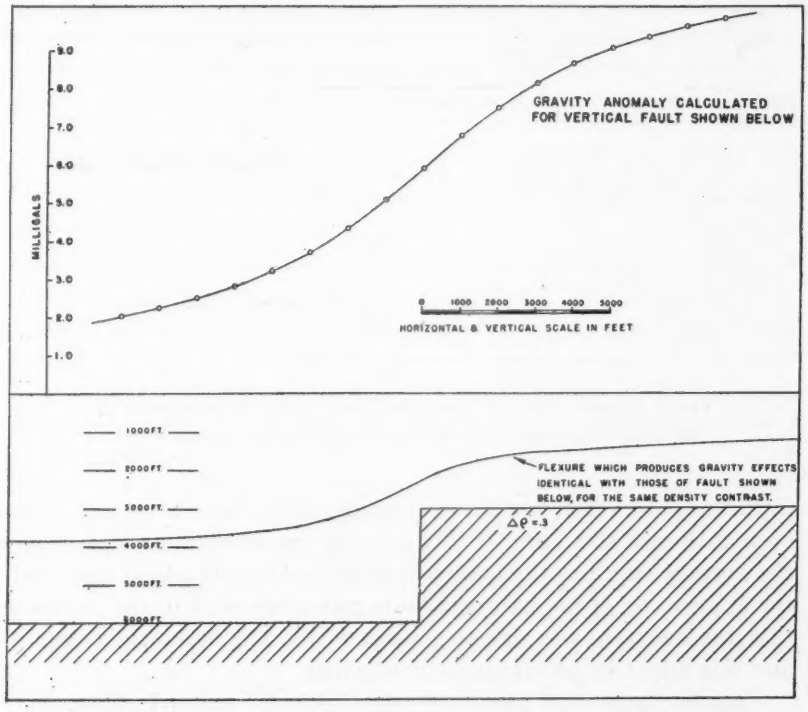

FIG. 4. Gravity profile for a vertical step fault, and, as an alternative solution, a flexure which would produce an identical gravity effect.

Probably the most widely used formula in gravity calculation is the "half-maximum" rule, which states that the depth to the center of a mass which has the shape of a horizontal circular cylinder of infinite length is equal to the distance on the ground from the point of maximum anomaly to the point where the anomaly has one-half its maximum value. The application of this rule to determine the depth of an actual structure may give a figure which is several times greater

than the true depth. As shown in Fig. 5, a broad anticline at a shallow depth can produce gravity effects which are identical with those for a much deeper cylinder. The center of gravity of the anticline shown is about 3500 feet; application of the "half-maximum" rule gives 10,000

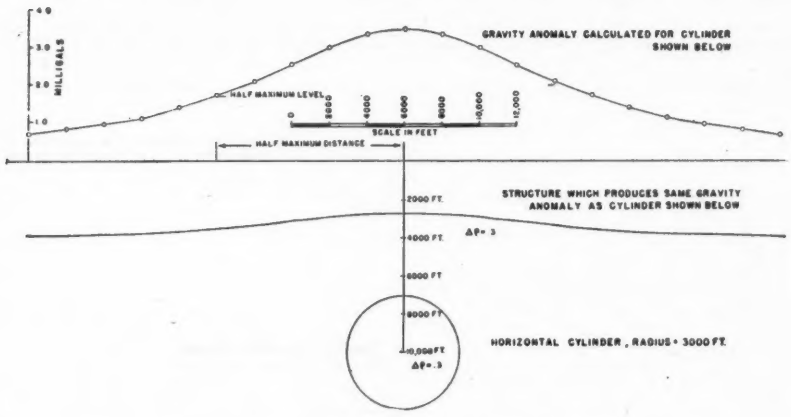

FIG. 5. Gravity effect of a horizontal cylinder and a broad anticline at much shallower depth which will produce an identical effect.

feet. And, of course, the same anomaly could have been due to an even shallower structure. If this anomaly occurred in an area where the average depth to the basement was known to be about 6000 feet, the application of the half-maximum rule could lead to the inference that the anomaly was due to a mass within the basement complex, and this might be an erroneous conclusion.

Besides these more familiar "rule-of-thumb" methods, there have been methods of direct interpretation proposed which involve considerable mathematics, and it is sometimes assumed that by such treatment the data are rendered less ambiguous. This is, of course, a fallacy, for the ambiguity is inherent in the nature of the gravitational field, that is, in the fact that different mass distributions can produce the same field, and no method of handling the data can alter this circumstance.

One of these more analytical methods was proposed by Evjen[2] and was more recently recommended by Pirson.[3] In this method the values

[2] H. M. Evjen, GEOPHYSICS, Vol. I, no. 1, Jan. 1936, pp. 127–136.

[3] Sylvain M. Pirson, *The Oil Weekly*, April 16, 1945, pp. 34–36, 42.

of gravity observed at the surface are used to calculate gravity at some depth below the surface, by means of MacLaurin's expansion,

$$g(h) = g(o) + hg'(o) + \frac{h^2g''(o)}{2!} + \frac{h^3g'''(o)}{3!} + \cdots .$$

where $g(o)$ is the value of gravity at a point on the surface, $g(h)$ is the value at a point directly below, at a depth h, and the primed quantities are successively higher derivatives of gravity with respect to h, or vertical gradients, which, as Evjen shows, can be calculated from the gravity data themselves.

In enumerating the advantage of the method, both Evjen and Pirson point to the lack of resolution in the ordinary gravity map, and show that separate masses are much better resolved on the calculated map for the deeper horizon. That is, the closer the plane on which the gravity observations are made (or calculated) is to the masses, the more closely does the gravity map resemble a structure contour map.

The "joker" in this method is that in order to apply it we must have some knowledge of the depth to the surface of density contrast. For if we make h larger than this depth, the calculated map is likely to resemble the structure *less* than does the observed map. For example, in Fig. 1, we might calculate gravity at a depth of 3000 meters; the resulting profile would presumably have two sharp maxima, and would resemble our configuration no. 6. But it may be that the true structure is shallow and more like configuration no. 1, which bears more resemblance to the observed gravity profile than it will to the profile calculated for a depth of 3000 meters. It seems that we can achieve by this method exactly what we achieved by the trial and error method; if we know the depth, we can calculate the structure, or something resembling the structure, or if we don't know the depth we can make the calculation for several depths and attempt to choose between the possible solutions on the basis of some other type of data.

Both Evjen and Pirson imply that the depth to the anomalous mass can be determined from the gravity data alone by using the expansion in vertical gradients. To quote from Pirson's last paragraph, "Another important advantage of the method resides in its ability to distinguish between a shallow and a deep mass anomaly. If the focusing of the measurements is made on a plane deeper than the anomaly producing mass the series expansion used in the calculation will diverge and will be unuseable for the stations immediately overlying the

shallow disturbing mass." This implies that we can find the depth to the mass by finding the largest value of h for which the series converges. This, of course, contradicts what we have been trying to demonstrate, which is that the depth is indeterminate from the gravity data alone. The error is to be found in the assertion that the series diverges when the depth h is greater than the depth of the mass which causes the anomaly. The series will surely diverge for some depth, but there is no valid reason for identifying this with the depth of the mass, for, as we have seen, the depth of the mass may be anything from zero to 3500 meters on the crest of the anomaly. It seems quite likely, if we consider Fig. 2, that the depth at which the series ceases to be convergent and becomes divergent is the same as our "limiting depth," that is, the depth to the crest of the deepest possible structure which will satisfy the anomaly. This may be, and usually is, considerably greater than the actual depth to the structure; it may be many times greater, if the structure is a typical anticline.

So far we have spoken only of data obtained by the gravity meter, that is, observations of the vertical gradient of the potential, $\partial U/\partial z$ or U_z. But it is possible by means of the torsion balance to observe other quantities, namely, U_{xz}, U_{yz}, U_{xy} and U_Δ. It might be supposed, and it has been implied in some of the literature on the torsion balance, that with all of these quantities at our disposal we should be able to determine the distribution of mass uniquely. Unfortunately this is not true, for all of the derivatives of a potential are mutually dependent. One of the fundamental theorems of potential theory is a corallary of Green's theorem, which states a relationship between potential and the surface integral of the vertical gradient of potential (gravity, or, in the magnetic case, vertical intensity). If U denotes the potential at some point (x_1, y_1, z_1) above the plane $z=0$, and if there are masses below this plane but none above, then

$$U = \frac{1}{2\pi}\int_S \frac{1}{R}\cdot\left(\frac{\partial U}{\partial z}\right)_{(x,y,0)} ds \qquad (1)$$

where $\partial U/\partial z$ is the vertical gradient of the potential (gravity) at the point $(x, y, 0)$ of the plane, R is the distance from the point (x_1, y_1, z_1) to the point $(x, y, 0)$ in the plane, and the integration is carried out over the entire surface of the plane.

This equation tells us, among other things, that the potential is completely defined in all of the space above the plane by the values of

gravity on the plane; and since the potential is defined by gravity, so are all of its derivatives. Since z_1 can be made as small as we please, the potential and its derivatives are defined on the plane itself as well as above it. By use of this formula we can calculate, theoretically at any rate, all of the torsion balance quantities, including curvature, from the gravity map on the plane. Therefore, if two distributions of mass produce the same gravity effects on the plane, they must also

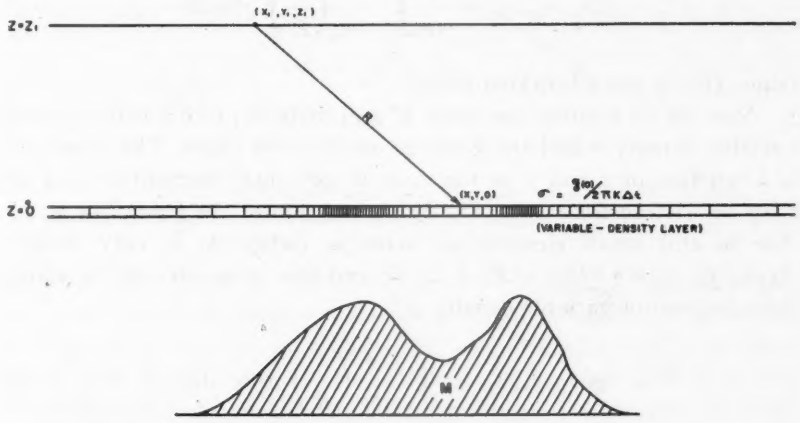

FIG. 6. The mass distribution, M, and the indicated surface distribution at the plane $Z=0$ produce identical gravity effects at a higher plane, $Z=Z_1$.

produce not only the same gradients, which is obvious from the nature of the gradients, but also the same curvature values. We cannot use curvatures, as has been suggested, to distinguish between two mass distributions which produce the same gradients or the same gravity.

Incidentally, this theorem also provides us with an analytical proof of the ambiguity of gravity interpretation, which was demonstrated empirically in Fig. 1. In Fig. 6 assume a known mass distribution M, a plane $z=0$ some distance above this mass, and a still higher plane $z=z_1$. The vertical component of attraction due to M at any point $(x, y, 0)$ of the $z=0$ plane we shall call $g(0)$, and by the theorem already stated, the value of the potential at a point (x_1, y_1, z_1) of the $z=z_1$ plane is given by

$$U(x_1, y_1, z_1) = \frac{1}{2\pi}\int_S \frac{1}{R} g(0)\,dS \qquad (2)$$

and the value of gravity on the $z=z_1$ plane due to the mass M is therefore

$$g(x_1, y_1, z_1) = \left(\frac{\partial U}{\partial z_1}\right)_{(x_1, y_1, z_1)} = \frac{\partial}{\partial z_1}\left[\frac{1}{2\pi}\int_S \frac{1}{R} g(o)dS\right]$$

or

$$g(x_1, y_1, z_1) = \frac{1}{2\pi}\int_S \frac{\partial}{\partial z_1}\left(\frac{1}{R}\right)\cdot g(o)dS \tag{3}$$

(since $g(o)$ is not a function of z_1).

Now let us remove the mass M and instead place a thin layer of variable density σ and thickness Δt on the $z=o$ plane. The density σ is a function of x and y, so the mass of any small element of area dS may be written $\Delta m=\sigma\cdot\Delta t\cdot dS$. The attraction at the point (x_1, y_1, z_1) due to this small element of mass is (when Δt is very small), $\Delta g(x_1, y_1, z_1)=K\partial/\partial z_1(1/R)\cdot\sigma\cdot\Delta t\cdot dS$ and the attraction of the whole infinite sheet of variable density is

$$g(x_1, y_1, z_1) = \int_S \frac{\partial}{\partial z_1}\left(\frac{1}{R}\right)\cdot\sigma\cdot\Delta t\cdot dS. \tag{4}$$

Comparing (3) and (4) we see that they are of the same form, and will be identical if we put $\sigma=g_0/2\pi K\Delta t$. This means that the thin layer of variable density on the plane $z=o$ produces the same gravitational effect on the higher plane $z=z_1$ as does the mass M. Therefore we have two distributions of mass which produce the same effect on the plane $z=z_1$. If the higher plane represents the surface of the ground, we can choose any plane below this surface and above M for the $z=o$ plane, so that we can have a multiplicity of variable density layers, each of which will produce the same gravity effects at the surface as does M.

It may, of course, be objected that the variable density layer is a fiction which does not correspond to anything in nature; and that this analysis does not prove that the anomaly can be satisfied by a multiplicity of structural configurations on a single horizon of density contrast. It was because of this objection that I preferred to use an empirical demonstration in Fig. 1. The objection is not a serious one, however, as long as the variable density layer is placed at some depth below the surface, for in that case the effect of the layer is very nearly

the same as the effect of a structural configuration on a single horizon of density contrast, $\Delta\rho$, in which the height of the structure is $k=\sigma\cdot\Delta t/\Delta\rho=g(o)/2\pi K\cdot\Delta\rho$ and with the average depth to the structure equal to the depth of the variable density layer.

Since equation (1) holds for any potential function, it also holds for magnetics; the magnetic potential and all of its derivatives are completely defined by the vertical intensity map (assuming it to be

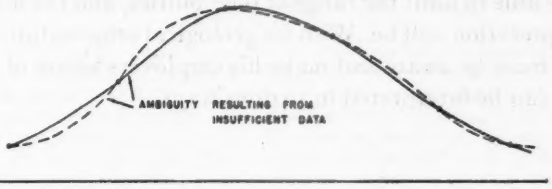

FIG. 7. Ambiguity from insufficient data. The two curves could have quite different interpretations but both fit all the points of control available.

accurate and sufficiently extensive). If two magnetic distributions can be found which satisfy the same set of vertical intensities (and just as in gravity, they always can be found), they will also satisfy the same set of horizontal intensity data. So combining horizontal with vertical intensity data does not give us a unique solution, as has been implied in some of the literature. Nor does observing magnetic effects at two or more levels resolve the ambiguity, for by means of the theorem it can be shown that if two magnetic distributions produce identical effects on one level they will also produce identical effects on all higher levels.

The foregoing remarks should not be construed as condemning the practice of combining different types of gravity and magnetic data for the purpose of completing the picture. In some cases, it is impossible to obtain the coverage desirable with one type of survey; for example, magnetic observations in a mine are severely restricted in areal extent; in such a case the addition of horizontal data to vertical data would greatly improve the interpretation. In jungle countries where gravity work is confined to certain trails and rivers, the addition of torsion balance gradients and curvatures would often improve the gravity map a great deal. Besides the fundamental ambiguity which we have been speaking of, which is inherent in the nature of the data, there is another kind of ambiguity which is due to the insufficiency and the

inaccuracy of our control, as is illustrated in Fig. 7. This kind of ambiguity can be resolved by obtaining more and better data.

But even with perfectly complete and perfectly accurate data, the fundamental ambiguity remains; a variety of interpretations are always possible, and the choice between them must rest on data of another kind, which, in most cases, is geological. The more geological data the interpreter can bring to bear upon the problem, the closer will he be able to limit the range of possibilities, and the less ambiguous his interpretation will be. With no geological information or with very little, he must be aware and make his employers aware of the fact that the data can be interpreted in various ways.

STUDIES ON SEISMIC WAVES: III. PROPAGATION OF ELASTIC WAVES IN THE NEIGHBORHOOD OF A FREE BOUNDARY*

C. Y. FU†

ABSTRACT

Continuous and spherical harmonic waves are generated at an internal point of the medium. By use of the classical method of Sommerfeld, the different modes of propagation near a free surface after the arrival of the waves are examined. Fro ı the approximate evaluations of the integrals, it is found that in addition to the ordinary types of body and surface waves, there are also inhomogeneous waves and surface waves which are not of the Rayleigh type. The amplitude factors of these latter waves vary inversely as the square instead of as the square root of the epicentral distance. Altogether, there are not less than five different types of waves and they are obtained from integrations in the neighborhood of the singularities of the integrals.

In the previous studies, discussions were confined to the case of infinite plane waves and the methods used are quite simple. However, this is an idealization which sometimes cannot be justified. Next in line in the order of simplicity are the continuous, spherical waves which will be dealt with in the present study.

The problem has been expertly investigated by Muskat[1] for two media in contact; but because of the mathematical complexity in this case, certain more detailed features of the integrals have not been discussed. For a semi-infinite medium, on the other hand, the calculations can be carried farther and the present study is somewhat along a similar line as his which essentially followed a method due to Sommerfeld. Since our emphasis is on the analysis of the possible types of waves, the potentials ϕ and ψ have not been converted into displacements in the final expressions; nor has the continuous wave been generalized into a pulse, because the result would be too complicated to be tractable.

Let the free boundary be the plane $z=0$ and the earth, assumed homogeneous, be the negative half space. Let a continuous wave be generated from a point source and it is assumed that the wave is dilatational, harmonic and possessing spherical symmetry. After reaching the boundary, the wave will contain both dilatational and

* By permission of the United Geophysical Company, Pasadena, California.

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[1] M. Muskat, Physics, vol. 4, 14–28, 1933.

distortional components. In the stationary state, the displacement components of a particle of the medium may be expressed in terms of the functions ϕ and ψ as follows:[2]

$$u = \frac{\partial \phi}{\partial r} + \frac{\partial^2 \psi}{\partial r \partial z}$$
$$w = \frac{\partial \phi}{\partial z} + \frac{\partial^2 \psi}{\partial z^2} + k^2 \psi \tag{1}$$

where u and w are the horizontal and vertical components respectively and k will be defined by the wave equation below. That the displacement can be so expressed presupposes an axial symmetry. The absence of the azimuthal component is justified by the fact that there is no occasion to give rise to this component when the source is of the kind assumed. Accordingly, in cylindrical coordinates, the dilatation Δ is given by

$$\Delta = \frac{\partial w}{\partial z} + \frac{1}{r} \frac{\partial}{\partial r} (ru)$$

and the equations of motion may be written as

$$\nabla^2 \phi + \frac{\rho \omega^2}{\lambda + 2\mu} \phi = \nabla^2 \phi + h^2 \phi = 0$$
$$\nabla^2 \psi + \frac{\rho \omega^2}{\mu} \psi = \nabla^2 \psi + k^2 \psi = 0 \tag{2}$$

where λ and μ are the Lamé constants of the medium, and ρ is its density. A time factor $e^{-i\omega t}$ with a *negative* exponent is understood but omitted in the sequel. We need also the stress-strain relations:

$$T_{zz} = \lambda \Delta + 2\mu \frac{\partial w}{\partial z}$$
$$T_{zr} = \mu \left(\frac{\partial \mu}{\partial z} + \frac{\partial w}{\partial r} \right) \tag{3}$$

where T_{zz} and T_{zr} are respectively the normal and tangential stress components. The boundary conditions for our problem are the vanishing of ϕ and ψ at infinity and the vanishing of the stresses at the free

[2] H. Lamb, Trans. Roy. Soc. Lond. A, vol. 104, 1–41, 1904.

surface. Substituting u and w from (1) and equating (3) to zero, we get immediately

$$2\frac{\partial}{\partial z}\left(\frac{\partial \phi}{\partial z}+\frac{\partial^2 \psi}{\partial z^2}+k^2\psi\right)+(2h^2-k^2)\phi=0$$
$$2\frac{\partial \phi}{\partial z}+2\frac{\partial^2 \psi}{\partial z^2}+k^2\psi=0 \tag{4}$$

at $z=0$. We are to solve (2) under the conditions (4). In order that the solutions be unique, they must also satisfy Sommerfeld's condition of radiation.[3]

The fundamental solutions of (2) in cylindrical coordinates are known to be

$$\phi = A'e^{\pm\sqrt{\xi^2-h^2}z}J_0(\xi r)$$
$$\psi = Be^{\pm\sqrt{\xi^2-k^2}z}J_0(\xi r)$$

where $J_0(x)$ is the Bessel function of zero order, ξ, a parameter and A' and B are independent of the coordinates. The signs of the radicals should be so chosen that ϕ and ψ vanish when $|z|$ is very large. In other words, the positive signs should be used if we are to deal with the negative half space. Since the wave equations are linear and A' and B may be regarded as functions of ξ, we can build up more general solutions by integrating these expressions with respect to ξ from 0 to ∞. Thus, we may write

$$\phi = \int_0^\infty A'(\xi)e^{+\alpha z}J_0(\xi r)d\xi,$$
$$z<0, \tag{5}$$
$$\psi = \int_0^\infty B(\xi)e^{+\beta z}J_0(\xi r)d,$$

where α and β are written for $\sqrt{\xi^2-h^2}$ and $\sqrt{\xi^2-k^2}$ respectively and the square roots themselves are taken as positive when ξ is large and positive. It is now possible to determine the functions $A'(\xi)$ and $B(\xi)$ so as to satisfy all the boundary conditions as well as the condition at the source.

Let us assume that a divergent, dilatational wave of the form

$$\phi_0 = e^{ihR}/R$$

[3] See, for instance, Baker and Copson, Huygens' Principle, p. 28.

is generated from a point source at a distance d below the origin, where the focal distance R is given by

$$R = \sqrt{(z + d)^2 + r^2}\,.$$

It is convenient to assume an image source of the same strength at a point which is at a distance d *above* the origin. This image wave function is of the form

$$\phi' = e^{ikR'}/R'$$

where R' is given by

$$R' = \sqrt{(z - d)^2 + r^2}.$$

This is permissible, because it satisfies the wave equation and gives rise to no additional singularity in the region $z<0$. With these sources ϕ_0 and ϕ', the solutions of (2) become

$$\begin{aligned} \phi &= \int_0^\infty A(\xi)e^{+\alpha z}J_0(\xi r)d\xi + \phi_0 + \phi', \\ \psi &= \int_0^\infty B(\xi)e^{+\beta z}J_0(\xi r)d\xi, \end{aligned} \tag{6}$$

and $A(\xi)$ and $B(\xi)$ can be determined by use of (4).

By means of the relations

$$\begin{aligned} e^{ikR}/R &= \int_0^\infty (\xi/\alpha)e^{-(z+d)\alpha}J_0(\xi r)d\xi, \qquad z + d > 0, \\ e^{ikR'}/R' &= \int_0^\infty (\xi/\alpha)e^{+(z-d)\alpha}J_0(\xi r)d\xi, \qquad z - d < 0, \end{aligned} \tag{7}$$

which were first given by Lamb, (6) may be transformed into

$$\begin{aligned} \phi &= \int_0^\infty A(\xi)e^{\alpha z}J_0(\xi r)d\xi + 2\int_0^\infty (\xi/\alpha)\cosh \alpha z e^{-\alpha d}J_0(\xi r)d\xi, \\ \psi &= \int_0^\infty B(\xi)e^{\beta z}J_0(\xi r)d\xi. \end{aligned} \tag{6a}$$

It is obvious that the second integral in ϕ does not contribute to the tangential stress at the boundary.

Substituting (6a) in (4) and equating the integrands (by Fourier-Bessel theorem), we have

$$\alpha(2\xi^2 - k^2)A + 2\alpha\beta\xi^2 B + 2\xi(2\xi^2 - k^2)e^{-\alpha d} = 0,$$

$$2\beta^2 B + k^2 B + 2\alpha A = 0.$$

These give

$$A(\xi) = -\frac{2\xi(2\xi^2 - k^2)^2 e^{-\alpha d}}{\alpha[2(\xi^2 - k^2)^2 - 4\alpha\beta\xi^2]}$$

$$B(\xi) = \frac{4\xi(2\xi^2 - k^2)e^{-\alpha d}}{(2\xi^2 - k^2)^2 - 4\alpha\beta\xi^2}. \tag{8}$$

Writing

$$F = (2\xi^2 - k^2)^2 - 4\alpha\beta\xi^2$$

$$f = (2\xi^2 - k^2)^2 + 4\alpha\beta\xi^2 \tag{9}$$

and substituting (8) in (6a), we obtain

$$\phi = 2\int_0^\infty \frac{\xi}{\alpha}\cosh \alpha z e^{-\alpha d} J_0(\xi r)d\xi$$

$$- 2\int_0^\infty \frac{\xi}{\alpha}\frac{(2\xi^2 - k^2)^2 e^{\alpha(z-d)}}{F} J_0(\xi r)d\xi, \tag{10}$$

$$\psi = \int_0^\infty \frac{4\xi(2\xi^2 - k^2)e^{\beta z - \alpha d}}{F} J_0(\xi r)d\xi.$$

The components of displacement may be obtained by substituting the last expressions in (1), whence we get, after some simplification,

$$u = \int_0^\infty \frac{\xi^2}{\alpha}\frac{f}{F} e^{\alpha(z-d)} J_1(\xi r)d\xi - \int_0^\infty \frac{\xi^2}{\alpha} e^{-\alpha(z+d)} J_1(\xi r)d\xi$$

$$- 4\int_0^\infty \frac{\beta\xi^2(2\xi^2 - k^2)}{F} e^{\beta z - \alpha d} J_1(\xi r)d\xi$$

$$w = \int_0^\infty \frac{4\xi^2(2\xi^2 - k^2)}{F} e^{\beta z - \alpha d} J_0(\xi r)d\xi - \int_0^\infty \frac{f}{F}\xi e^{\alpha(z-d} J_0(\xi r)d\xi \tag{11}$$

$$- \int_0^\infty \xi e^{-\alpha(z+d)} J_0(\xi r)d\xi.$$

These hold for any point in the field where $|z| < d$. When $z = 0$,

$$u_0 = \int_0^\infty 2\beta(2k^2\xi/F)e^{-\alpha d}J_1(\xi r)d\xi,$$
$$w_0 = \int_0^\infty (2\xi^2 - k^2)(2k^2\xi/F)e^{-\alpha d}J_0(\xi r)d\xi. \tag{11a}$$

The last expressions may be compared with those obtained by Lamb.[4]

For all the integrals in the previous equations, the range of ξ is from o to ∞ along the real axis. In this connection, it should be pointed out that the quantities h and k in the expressions α and β are both real in accordance with their definitions in (2). To apply the formulae (7), the paths of integration have to be indentated below the real axis.[5] But this would leave some doubt as to the applicability of the Fourier-Bessel theorem. To avoid this difficulty, we may assume that h and k are at first both complex quantities with *positive* imaginary parts. This would amount to assuming that the medium is absorptive for both dilatational and distortional waves. In the final formulae, we may make h and k approach the real axis from the first quadrant in the ξ-plane to signify that the absorption of the medium is vanishingly small. This limiting process is certainly justified from physical considerations.

In order to make use of the theorems for contour integrals, we shall deform these essentially real paths of integration into the complex domain. But the Bessel function J_n of the first kind and any order n increases indefinitely if its argument becomes very large and imaginary. However, we can split J_n into the two Hankel functions,

$$2J_n = H_n^{(1)} + H_n^{(2)}$$

where $H_n^{(1)}$ is convergent in the first quadrant and $H_n^{(2)}$ in the fourth in the plane of its argument.

Consider, now, an integral of the form

$$I = \int_0^\infty E(\xi)\xi J_0(\xi r)d\xi$$

where $E(\xi)$ is an even function of ξ. In terms of Hankel functions, this may be transformed into

$$I = 1/2\int_0^\infty E(\xi)\xi H_0^{(1)}(\xi r)d\xi + 1/2\int_0^\infty E(\xi)\xi H_0^{(2)}(\xi r)d\xi.$$

[4] H. Lamb, *op. cit.*

[5] Watson's Bessel Functions, p. 416.

But

$$H_n^{(2)}(xe^{i\pi}) = e^{(n+1)i\pi}H_n^{(1)}(x).$$

Changing the variable ξ to $-\zeta$, we reduce the second integral in I into the same form as that of the first, except that the limits are from $-\infty$ to o. Combining the two integrals, we have

$$I = 1/2\int_{-\infty}^{+\infty} E(\xi)\xi H_0^{(1)}(\xi r)d\xi. \tag{12}$$

In this form, the path of integration is easily deformed. Accordingly, we may rewrite (10) as follows:

$$\begin{aligned}\phi &= \frac{e^{ihR}}{R} + \frac{e^{ihR'}}{R'} - \int_{-\infty}^{+\infty} \frac{\xi}{\alpha}\,\frac{(2\xi^2 - k^2)^2}{F}\,e^{\alpha(z-d)}H(\xi r)d\xi \\ &= \frac{e^{ihR}}{R} - \frac{e^{ihR'}}{R'} - \int_{-\infty}^{+\infty} \frac{4\xi^3\beta}{F}\,e^{\alpha(z-d)}H(\xi r)d\xi \qquad (13) \\ \psi &= \int_{-\infty}^{+\infty} \frac{2\xi(2\xi^2 - k^2)}{F}\,e^{\beta z - \alpha d}H(\xi r)d\xi\end{aligned}$$

where H is written for $H_0^{(1)}$.

To evaluate these integrals exactly is not simple, but it is not difficult to make rough estimations. For this purpose, we note that the two branch points of the integrands are given by

$$\alpha = o, \quad \text{and} \quad \beta = o,$$

and the poles by the roots of

$$F(\xi) = o, \tag{14}$$

which can be reduced to a cubic in ξ^2/k^2. Lamb has shown that if h and k are real, there is only one real root possible for the present problem and it is slightly greater than 1. For a Poisson solid ($\lambda=\mu$), this real root is $\xi_0^2/k^2 = 1.087664$. The two other roots are complex conjugates. We shall show that they are not important.

In accordance with our previous determination of the signs of the square roots, we may locate the three singular points of the integrals as in Fig. 1, where $h<k<\xi_0$. The negatives of these three points must all lie in the third quadrant. Let two branch cuts be drawn from the branch points h and k upwards to infinity in such a way that along each of them, the real part of α or β remains zero. (It should be noticed that when the absorption of the medium is small, these cuts will

be very close to the axes. However, this does not involve a difficulty in the following calculations. There is also no difficulty in making the imaginary parts of h and k small in the final formulae. The analytical justification of this point has been examined by Joos and Teltow.[6])

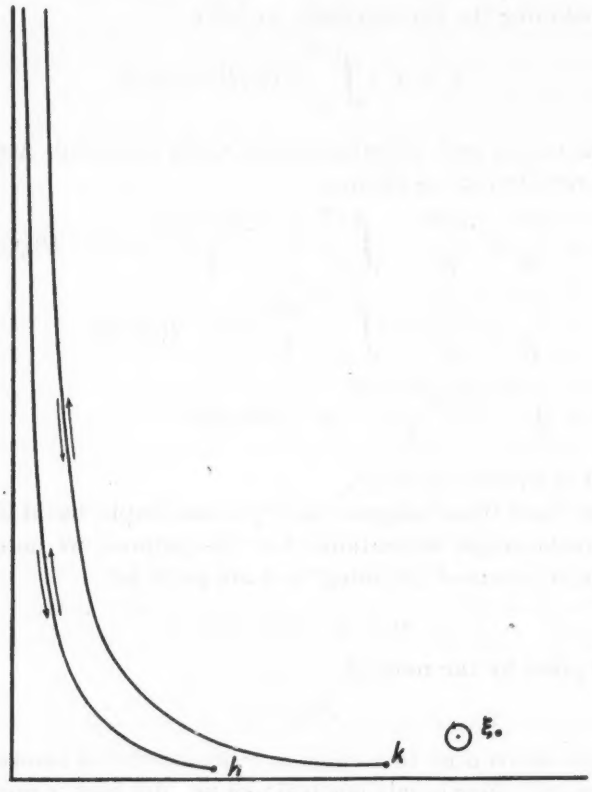

FIG. 1. The ξ-plane.

Deform the path of int[illegible] which is from $-\infty$ to $+\infty$ along the axis of reals into the pa[illegible] the two sides of the cuts and around the pole in the sense [illegible] by the arrows. The connecting contour at infinity contributes n[illegible]ng to the integral on account of the behavior of the function $H_0^{(2)}$. Thus, each of the integrals in (13) is equal to the sum of three integrals: one around the pole and two along the cuts.

[6] G. Joos and J. Teltow, Phys. Zeit. Bd. 40, 289–293, 1939.

We will now follow the method of Sommerfeld in his famous work on the propagation of electromagnetic waves.[7] By the theorem of residues, the integral around the pole in the expression for ϕ is given by

$$P_\phi = -2\pi i \cdot 4\xi_0^3\beta_0 e^{\alpha_0(z-d)} H(\xi_0 r) \lim_{\xi\to\xi_0} \frac{\xi - \xi_0}{F(\xi)}$$
$$= -8\pi i \xi_0^3 \beta_0 e^{\alpha_0(z-d)} H(\xi_0 r)/F'(\xi_0),$$

where ξ_0 is the root of $F(\xi)=0$, F' is the derivative of F with respect to ξ and

$$\alpha_0 = \sqrt{\xi_0^2 - h^2}, \qquad \beta_0 = \sqrt{\xi_0^2 - k^2}.$$

Substituting in this the asymptotic expression

$$H_0^{(1)}(\xi r) \sim \sqrt{\frac{2}{\pi \xi r}}\, e^{i(\xi r - \pi/4)}$$

we obtain

$$P_\phi \sim -\frac{8\sqrt{2\pi}\, e^{i\pi/4}\xi_0^{5/2}\beta_0}{F'(\xi_0)} \frac{1}{\sqrt{r}} e^{\alpha_0(z-d)} e^{i\xi_0 r} \qquad (15)$$

when $z<0$. Similarly, for the corresponding integral in the expression for ψ we find

$$P_\psi \sim \frac{4\sqrt{2\pi}\, e^{i\pi/4}\sqrt{\xi_0}\,(2\xi_0^2 - k^2)}{F'(\xi_0)} \frac{1}{\sqrt{r}} e^{\beta_0 z - \alpha_0 d} e^{i\xi_0 r} \qquad (16)$$

when $z<0$.

Both (15) and (16) contain the factor $e^{i\xi_0 r}$. It is due to this that the complex roots of (14) may be disregarded, because that with the negative imaginary part is outside of our region of interest and that with the positive imaginary part will lead to a wave which is exponentially damped in the direction of r and therefore may be neglected when r is not small.

In the approximate evaluation of the integral along the cut, it should be pointed out that the path we have chosen is not the one of the steepest descent. The saddle point method may be used in the present problem to get more terms in the asymptotic expansions, as has been done, for example, by T. Sakai,[8] but the procedure we are

[7] A. Sommerfeld, Ann. d. Phys. Bd. 28, 665–736, 1909.

[8] T. Sakai, Physico-Math. Soc., Proc. Japan, vol. 15, 291–327, 1933.

going to follow is so much simpler, though not as accurate, and the physical meaning of the result is also easy to grasp. It is felt that in a mathematical idealization of a practical problem, which in reality is much more complex, what we can hope to explain with confidence are sometimes merely the dominant features. For this reason, a simpler but approximate treatment is not without some advantage. The method is based on the use of the following formula,

$$\lim_{r\to\infty} \int_0^{i\infty} f(t)e^{itr}\frac{dt}{\sqrt{t}} = f(0)\sqrt{\pi/r}\, e^{i\pi/4} \tag{17}$$

which is one type of a Laplace integral, and in which $f(t)$ is assumed to be finite and continuous. The validity of this formula depends on the fact that when r is large, only the term with a small t is significant in $f(t)$. Taking $f(t)\sim f(0)$ out of the integral sign, we can integrate the left hand side immediately and obtain the result indicated. It is evident that the result derived from the use of (17) cannot be expected to be valid when r is small. Our objective, then, is to transform our integral into the form of the left hand side of (17). It is interesting to note, however, that the relation (17) is still true if the upper limit of the integral is ∞ instead of $i\infty$. The two cases are valid for different reasons. When the limit is imaginary, we have a rapidly decreasing exponential function in the integrand, but when the limit is real, we have a rapidly oscillating function if t is not small. So we can still apply the above formula even if we had drawn our path of integration along the real axis as was done by Lamb.

For the integral

$$\phi_h = -\int \frac{4\beta\xi^3 e^{\alpha(z-d)}}{F} H(\xi r)d\xi$$

along the two sides of the cut from h, let us first integrate it by parts. Noting that

$$\int H(\xi r)\xi d\xi = -H'(\xi r)\xi/r$$

we obtain

$$\phi_h = -\int \frac{4}{r}\xi H'(\xi r)\frac{d}{d\xi}\frac{\beta\xi^2 e^{\alpha(z-d)}}{F}d\xi.$$

Let $\alpha^2 = -\eta^2$. Then, along one side of the cut, $\alpha = -i\eta$, and along the

other, $\alpha = +i\eta$. By use of the relation $d\eta/d\xi = -\xi/\eta$, and the asymptotic expansion

$$H'(\xi r) \sim \sqrt{\frac{2}{\pi \xi r}}\, e^{i(\xi r + \pi/4)}$$

the above integral may be written as

$$\phi_h \sim \frac{4}{r}\sqrt{\frac{2}{\pi r}}\, e^{i\pi/4} \int \frac{\xi\sqrt{\xi}}{\eta}\, e^{i\xi r} d\xi \cdot \frac{d}{d\eta}\, \frac{\beta \xi^2 e^{\alpha(z-d)}}{F}$$

where the limits of integration correspond to $\eta = -\infty$ and $\eta = +\infty$. Transforming again by the substitution $t = \xi - h$, we arrive at the expression

$$\phi_h \sim \frac{4i}{r}\sqrt{\frac{2}{\pi r}}\, e^{i(hr + \pi/4)} \int \frac{\xi\sqrt{\xi}}{\sqrt{\xi + h}}\, e^{itr} \frac{dt}{\sqrt{t}}\, \frac{d}{d\eta}\, \frac{\beta \xi^2 e^{\alpha(z-d)}}{F} \qquad (18)$$

where t extends from $i\infty$ to o on one side of the cut and from o to $i\infty$ on the other side. Since $\sqrt{t}$ changes sign on different sides of the cut, the integral is double the value obtained by integrating from o to $i\infty$. If we write

$$f(t) = \frac{\xi\sqrt{\xi}}{\sqrt{\xi + h}}\, \frac{d}{d\eta}\, \frac{\beta \xi^2 e^{\alpha(z-d)}}{F}$$

then (18) is of the form of (17). Now, when $t \to o$, $\xi \to h$, $\alpha \to o$ and $\eta \to o$. Moreover,

$$\beta = \sqrt{-\eta^2 + h^2 - k^2}$$

and

$$F = (-\eta^2 + 2h^2 - k^2)^2 + 4i\eta(\eta^2 - h^2)\sqrt{-\eta^2 + h^2 - k^2}.$$

Hence, if $|z|$ is of a moderate value and is small compared with r, we have

$$f(o) = f(t)_{\eta \to o} = \frac{ih}{\sqrt{2}}\, \frac{h^2\sqrt{h^2 - k^2}}{(2h^2 - k^2)^2} \left[\frac{4h^2\sqrt{h^2 - k^2}}{(2h^2 - k^2)^2} - (z - d) \right].$$

With this, we obtain finally the dominant term of (18)

$$\phi_h \sim \frac{8h^3\sqrt{k^2 - h^2}}{(2h^2 - k^2)^2} \left[\frac{4ih^2\sqrt{k^2 - h^2}}{(2h^2 - k^2)^2} + (z - d) \right] \frac{e^{ihr}}{r^2} \qquad (19)$$

which is valid below and near the free surface. The wave amplitude in the last formula cannot decrease indefinitely with z, because when $|z|$ is large, the approximate formula does not hold.

In a similar manner, we can estimate the value of the integral

$$\psi_h = \int \frac{2\xi(2\xi^2 - k^2)}{F} e^{\beta z - \alpha d} H(\xi r) d\xi$$

for the distortional wave along the cut through h. The result is

$$\psi_h \sim \frac{4h}{2h^2 - k^2}\left[\frac{4h^2\sqrt{k^2 - h^2}}{(2h^2 - k^2)^2} = id\right]\frac{1}{r^2} e^{i(hr - \sqrt{k^2-h^2}z)}. \quad (20)$$

Along the cut through k, we can apply the same method. The calculations will not be repeated here. The results are as follows:

$$\phi_k \sim -\frac{8i}{k} e^{\sqrt{k^2-h^2}(z-d)} \frac{e^{ikr}}{r^2} \quad (21)$$

$$\psi_k \sim \frac{4i}{k}\left[\frac{4\sqrt{k^2 - h^2}}{k^2} + z\right] e^{-\sqrt{k^2-h^2}d} \frac{e^{ikr}}{r^2}. \quad (22)$$

All these are valid when z is negative and not large. We see then that the wave functions ϕ and ψ in (13) are composed of the partial wave functions ϕ_0, ϕ', P_ϕ, P_ψ, ϕ_h, ϕ_k, ψ_h, and ψ_k. We shall discuss the physical meaning of each of these in turn.

The components ϕ_0 and $-\phi'$ represent two spherical waves whose amplitudes vary inversely as the distance on account of the spherical divergence, but they are opposite in phase. The function ϕ_0 represents the incidence wave; $-\phi'$ may be interpreted as representing the reflected wave. For lack of a better name, we may call these the first order terms because of the inverse first power in r. When d is small or when r is large (compared with the wave length), these two terms will effectively interfere with each other. For plane waves, we can expect a complete interference, but for spherical waves, $\phi_0 - \phi'$ approaches zero as $1/r^2$. This residual disturbance,[9] together with the wave components (18)–(22), whose amplitudes are all of the order of $1/r^2$ when z is of moderate value, we shall call the second order effect,

[9] This effect has been mentioned in the well known paper by H. Weyl in Ann. d. Physik 60, p. 486, 1919. The second order effects have been made the subject of a particular study on electromagnetic waves by H. Ott in Ann. d. Physik (5)41, 443–466, 1942.

and it will not exist if only plane waves are considered. It must be attributed to the curvature of the incident wave front.

The expressions in (15) and (16) represent nothing else than surface waves of the Rayleigh type. This is evident from the denominators and the exponential factors. In a two dimensional divergence, the constancy of the total energy flux requires that the amplitude must decrease as $1/\sqrt{r}$. Since we are dealing with negative values of z only, the factors $e^{\alpha_0 z}$ and $e^{\beta_0 z}$ indicate the exponential decrease of the amplitude with depth. The factor $e^{-\alpha_0 d}$ occurring in both P_ϕ and P_ψ indicates that the amplitude also decreases exponentially, with the depth of the source. The velocity of either of these waves is given by $V_R=\omega/\xi_0$. When the Poisson ratio of a solid is 0.25, $\xi_0=1.08766\ k$. Hence, $V_R=0.9194\ V_s$ where V_s is the velocity of the transverse waves.

The wave expressed by (19) is entirely of a different nature. First, of all, the amplitude decreases inversely as the square of the epicentral distance r. It is therefore a second order effect when r is large. Secondly, the surface of constant phase is given by

$$r = \text{constant},$$

which is perpendicular to the free boundary, but the surface of constant amplitude is given by

$$A_h/r^2 = \text{constant},$$

where A_h is written for

$$\frac{8h^3\sqrt{k^2-h^2}}{(2h^2-k^2)^2}\left[\frac{4h^2\sqrt{k^2-h^2}}{(2h^2-k^2)^2}\,i+(z-d)\right]$$

which consists of two components differing by a phase of $\pi/2$. A_h decreases linearly as we go down from the surface. However, the formula will not hold when $-z$ is large

Expression (20) represents the reflected transverse wave when the dilatational wave is almost at grazing angle of incidence. It is a second order effect. The surface of constant phase of this wave is inclined at an angle

$$\theta = \tan^{-1} h/\sqrt{k^2-h^2} = \sin^{-1} h/k = \sin^{-1} V_s/V_p$$

to the surface and is just equal to the critical angle for the transverse wave. The velocity of this wave is given by

$$V = \omega/\sqrt{h^2 + (k^2 - h^2)} = \omega/k = V_s.$$

The factor

$$B_h = -\frac{4h}{2h^2 - k^2}\left[\frac{4h^2\sqrt{k^2 - h^2}}{(2h^2 - k^2)^2} + id\right]$$

also consists of two components with a phase difference of $\pi/2$.

In (21), the factor $e^{\sqrt{k^2-h^2}z}$ signifies an exponential decrease of the wave amplitude with depth, but this wave differs essentially from that of Rayleigh in two respects: first, the amplitude factor varies inversely as the square of r instead of as the square root; secondly, the wave velocity is given by $V=\omega/k=V_s$ which is the same as the transverse wave velocity. However, the wave itself is of a dilatational nature. We obtain here a new type of surface weave.

Finally, the expression (22) represents again an inhomogeneous wave, viz., one in which the surface of constant phase and that of constant amplitude do not coincide. Being a transverse body wave, it travels with a velocity V_s and in a direction parallel to the free surface. Although there are two terms in the factor

$$B_k = \frac{4i}{k}\left[z + \frac{4\sqrt{k^2 - h^2}}{k^2}\right]$$

there is no phase difference between them. Both (22) and (21) contain the exponential factor $e^{-\sqrt{k^2-h^2}d}$. They are therefore very sensitive to the depth of the source and become inappreciable when d is large.

Even though we do not intend in the present work to generalize our results to the case of an impulsive source, we may point out one fact without further calculation. We have assumed a spherical wave source which contains an amplitude factor of dimension L^{-1}. When the amplitude factor of a component wave is not of the first power in $1/r$, it must contain some power of h or k (each of dimension $1/L$) in order to make up for the correct dimension. This will lead to a dependence of the amplitude on frequency. A consequence of this effect is the spreading of a sharp pulse on reflection.

A serious condition on the preceding method of solution is the limitation to large epicentral distances. Firstly, we have used the asymptotic expression of the Hankel function which is quite accurate (to a few percent) so long as its argument is not too small, say, not less than 3. This means, in the present problem, when r is larger than half the

wave length. Secondly, in using (17), we have neglected $1/r^2$ in comparison with $1/r$. The method therefore yields no information when r is small.

The separation of a disturbance into these wave components is the result of an approximate evaluation and it is only formal. A word must be said concerning their physical reality. The first order waves and the Rayleigh waves have all been observed and also the reflected transverse wave. But those expressed by (19), (21) and (22) arrive at the same time as the ordinary body waves and what we can observe are the resultant disturbances. Their separate existence might be very difficult to confirm. Furthermore, care must be taken in applying this same method to other more complicated problems, because mathematically, the approximation will be too rough if the pole of the integrand is very near to the branch point. In that case, the formal separation of the disturbance would involve gross inaccuracy and a more rigorous method should be used.

The present paper is the revision of a research report submitted to the United Geophysical Company in Pasadena more than two years ago. I wish to thank the management of that company for permission to publish these results.

FLUORESCENT TECHNIQUES IN PETROLEUM EXPLORATION

JACK DE MENT*

ABSTRACT

New methods of petroleum location, detection and analysis, based on the fluorescence characteristic shown by all crude oils are described. A brief review is given of the available techniques and instruments used in fluorochemical analysis, and emphasis is placed on fluorographic exploration by means of subsurface soil samples, as well as the fluorologging of wells. The author has not limited himself to a review of the field, but has also pointed out, on the basis of the existing data of fluorochemistry, approaches to problems in the petroleum field which have proven successful in other branches of radiation science. The paper contains 43 references and 7 illustrations.

INTRODUCTION

It is seldom that the various phases in the genesis of a science are clear cut and distinctive. In the case of the application of fluorochemical knowledge to geophysical exploration a definite date of origin is difficult to determine. Fluorochemical methods are among the youngest of the newer tools of chemistry and physics and biology which have been adopted for oil detection. The data of fluorochemistry can be included among those techniques of apparently unrelated specialties in chemistry and physics which, during the last decade, have made their entrance into geophysical exploration methods.

The fluorescence characteristic of petroleum has probably been recognized since the earliest days of antiquity. This property has, in past years, been known from the fact that crude petroleum is occasionally of a clear color when taken from the earth, but is generally of a greenish color by reflected light, appearing claret-red by transmitted light. As the color of the oil darkens, the greenish color seen in reflected light may become so deep as to appear black.

BASIC THEORY

Fluorochemistry is that science which embraces the theory and applications of luminescence and radiation in physicochemical science.[1] In a physical sense, it deals with the action of radiation upon matter

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[1] J. De Ment, *Fluorochemistry*, New York, Chemical Publishing Co., 1945. (This work contains an extensive list of works in the field.)

and vice versa, excepting photochemical reactions as such, and having its foundations in the absorption by matter of quanta and their subsequent emission as light. This quantum capture-release process is the mechanism basic to all fluorochemical theory, and from it has developed much of our newer knowledge about the characteristics of various forms of light energy, as well as the construction and behavioristic qualities of matter.

A number of monographs and treatises have been written on luminescence and related subjects, and for a thorough theoretical background of fluorochemical methods of geophysical exploration, it is advisable to become familiar with the fundamentals in this field.[1–3] Likewise, an extensive literature is available on that branch of analytic science known as fluorochemical analysis, an understanding of which is recommended in view of the numerous and otherwise specialized physical and chemical methods which are now being adapted to the petroleum field.[4–7]

Luminescence is technically defined as the emission of light by matter under the influence of energy, such a light emission violating Kirchhoff's law of black body radiation.[2] Two types of luminescence are generally recognized: One, called fluorescence, lasts only as long as the matter is under the influence of the exciting energy. The other called phosphorescence, persists after the source of exciting energy has ceased to influence the matter. The fluorescence corresponds to the popular designation of "glow," that of phosphorescence to "afterglow." Both fluorescence and phosphorescence are closely related, and the distinction between the two is phenomenological and historical rather than scientific.

The favored excitant is ultraviolet light rendered free of visible light by means of suitable glass or other filters. Crude petroleum oils

[2] P. Pringsheim and M. Vogel, *Luminescence and Its Practical Applications*, New York, Interscience Publishers, 1943.

[3] H. C. Dake and J. De Ment, *Fluorescent Light and Its Applications*, New York, Chemical Publishing Co., 1941.

[4] J. Radley and J. Grant, *Fluorescence Analysis in Ultra-Violet Light*, 3d. edition, New York, 1939.

[5] P. Danckwortt, *Lumineszenz-Analyse im Filtrierten Ultravioletten Licht*, 4th Aufl., Leipzig, Akademische Verlagsgesellschaft, 1940.

[6] M. Haitinger, *Die Fluoreszenzanalyse in der Mikrochemie*, Wien und Leipzig, Emil Haim, 1937.

[7] J. De Ment, *Fluorescent Chemicals*, vol. 4, *Fluorochemical Analysis*, 2d edition, New York, Chemical Publishing Co., 1946 (in press).

respond to all wavelengths of ultraviolet light, as well as to short wavelength visible rays, as will be described subsequently, but for convenience and reliability, the ultraviolet lamp proves superior to all other forms of energy sources.

Several different ultraviolet lamps are available, and an abundant literature exists on the relative merits of the various units for fluoro-

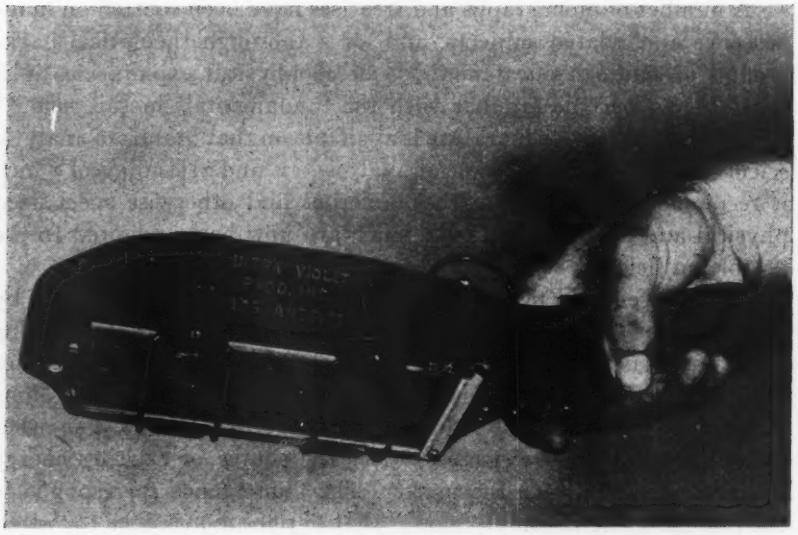

FIG. 1. Large cold-quartz mercury arc, hand ultraviolet lamp, with filter, employed in studies on petroleum-bearing rocks and earths.

chemical work.† However, the mercury arc is the more widely used source of ultraviolet light. Mercury arcs create two predominant types of ultraviolet rays depending upon the design and operational characteristics of the arc. The low-pressure mercury arc, possessing a silica or quartz envelope, operating at high potentials with small current consumption, is commonly known as the "cold-quartz unit," since it generates very little heat. The low-pressure unit emits "short wave-

† Representative ultraviolet light units of commerce include the low pressure Hg. arc, called the "Mineralight," which is manufactured by Ultra-Violet Products, Inc., 5205 Santa Monica Blvd., Los Angeles 27, California, and the high pressure Hg arc, called the "H" series units, manufactured by General Electric Company, Schenectady, New York. Glass filters which pass the ultraviolet and exclude substantially all of the visible can be secured from Corning Glass Works, Corning, N. Y. and from Kopp Glass, Inc., Swissvale, Pa.

length" ultraviolet light, most of its radiation output being concentrated at 2537 Å. In contrast to this, the high-pressure mercury arc operates at higher temperatures, lower voltages, but with more current consumption, issuing radiation principally in the "long wavelength" regions at about 3650 Å.

Luminescent systems are of two kinds, both of which enter into the theory and application of fluorochemistry to oil work.[1] The homogeneous luminescent system consists of matter in which all particles are identical, i.e., possessing no impurities, and, in the case of solids, ideal crystallographic and stoichiometric characteristics. In the case of liquids, many highly purified organic compounds conform to the requirements for a homogeneous luminescent system. The heterogeneous luminescent system, in contrast to the former, contains impurities and structural imperfections, either or both of which may enter into the luminescence. Solid heterogeneous luminescent systems are exemplified by the light emitting solids called phosphors, which contain a trace of activating material, usually a metallic salt of a high atomic order, in solid solution in a bulk of relatively inert solvent. Liquid heterogeneous systems are illustrated by crude oil, which contains many different organic substances, one or more giving rise to the response to ultraviolet light or other forms of energy. Petroleum dissolved in a liquid solvent, like benzene, also comprises a heterogeneous luminescent system.

SUBJECTIVE METHODS OF FLUOROANALYSIS[1–7]

The simplest method of ascertaining the fluorescence characteristic of a substance, such as oil, is to examine a sample with the unaided eye under filtered ultraviolet light, as well as under other radiations known to excite luminescence. If employed by an experienced operator, the subjective method will yield satisfactory qualitative results and, in some instances, good quantitative data if comparison standards are relied upon. However, there are many pitfalls in observing fluorescence, and the technician should have sufficient experience in the work to avoid them. Thus, the eye itself may be a source of trouble for this device is quite unreliable in the discrimination of color and brightness. This is aside from the fact that color blindness is not unknown among men of science.

It should be understood that none of the glass ultraviolet filters in widespread use is capable of attenuating all visible wavelengths. Some purple, blue and red radiations invariably pass through these glasses, but ordinarily this is not objectionable. However, one can

confuse the effect of purple radiations from the light source with fluorescence.

In actually observing the fluorescence of a specimen of drill core, or an extract of cuttings, the exciting beam should be allowed to strike the sample or vessel at right angles to the line of observation. It is often preferable to allow the exciting beam to strike an exposed surface of the sample, dispensing with a possible source of error in the fluorescence of the container. This is especially true when short wavelength radiations are being employed, for many glasses not only fluoresce under this light, but may be quite opaque. It is true to a less degree when long wavelengths are used. Thus, glass vessels of fused silica, Corex and Uviol provide the most satisfactory results. Inert metal containers with a black coating, such as burnished copper dishes, may also be employed. A variety of laboratory ware constructed from non-fluorescent, black porcelain is now available, and vessels of this material will yield good results.‡

For the more specialized, instrumental forms of analysis, the test tubes, cuvets and accessory apparatus supplied by the manufacturer prove satisfactory, since care is generally taken to secure the best type of items for these purposes. The present writer[8] has constructed glassware, such as cuvets, from the filter glass used to exclude visible rays from the beam, and these vessels have proved highly satisfactory for fluorescence observations. A cuvet may be made with walls of Corning Glass number 986, the exciting beam being allowed to pass through the walls of the cuvet into the solution, and the observation being made through the open top at right angles.

In field or laboratory observations of fluorescence, the eye should always be given time for dark adaptation. After five or more minutes' rest in darkness, the equivalent of which may be achieved by wearing dark red glasses before the examination, scotopic vision comes into play, in which condition the eye is some 200,000 times more sensitive to light than with daytime or photopic vision.

The inspection should be made in a darkened room, in the absence of foreign bodies which show fluorescence. In the field, a black cloth hood will permit fairly reliable observation, but it is advisable to employ an inspection cabinet specially developed for field work.§ The

‡ Manufactured by the Coors Porcelain Company, Golden, Colorado.

[8] J. De Ment, Unpublished Work, Portland, Oregon, 1945.

§ Manufactured by the Ultra-Violet Products, Inc., Los Angeles 27, California.

inspection cabinet permits manual operation within a light-tight enclosure, comparison of samples under optimal conditions, and such devices are portable and self-contained (Fig. 2).

OBJECTIVE METHODS OF FLUOROANALYSIS

The previously described subjective methods of fluorochemical analysis are not to be discounted, since fluorescence provides a type of reaction which is not paralleled by either chemical or physical

FIG. 2. An Ultra-Violet Products Fluorescence Inspection Cabinet designed for small scale field work. The more elaborate units are equipped with viewing aperture, arm-holes, sample holders, and the like, permitting quantitative fluoroanalysis by comparison with standards.

methods of analysis, and the factors entering into the production of a certain fluorescence or response to ultraviolet light are frequently so complicated that identity of appearance is strong evidence of composition, source, and history of any two or more objects. Thus, the unaided eye observation of fluorescence under satisfactory conditions proves suitable for a great deal of work in petroleum science, although considerable extensions in delicacy and accuracy, as might be expected, are achieved by the use of objective, instrumental means.

Every luminescent substance exhibits certain distinguishing fluorochemical characteristics. Since luminescence is generally visible light, with perhaps a varying admixture of ultraviolet and infrared wavelengths, depending upon the substance, the methods and criteria employed in optics may serve in an analytic capacity. This means that fluorescent light can be subjected to photometric, spectrometric, and spectrophotometric determinations. Likewise, since the luminescent system must absorb light before an emission can take place, the absorption characteristics of that system may be studied. With the distinction in mind between fluorescence and phosphorescence, it is evident that the lifetime of the emission may be a distinguishing property of light-emitting systems.

These purely physical techniques reinforce a number of chemical and physicochemical methods of analysis which have proven of value in petroleum work. It is not necessary to discuss here in detail the relative merits or limitations of each of the fluoroanalytic methods, since a considerable literature is devoted to that subject,[1-7] but a brief resumé will be in order so that their application to the specialized field of petroleum detection and assay can be more adequately appraised.

FLUOROMETRY

The photometry, i.e., the determination of intensity, of fluorescence is called fluorometry. The intensity of fluorescence, being quite dependent in many cases upon chemical and physical conditions and upon the nature of the exciting radiation and its wavelength, yields valuable information about the kind and concentration of a luminescent substance in solution. Roughly, fluorescence intensity depends upon several factors: (1) The concentration of the fluorescent substance in solution; (2) the intensity and wavelength of the exciting light; (3) the pH and temperature of the solution; (4) the nature of the solvent; and (5) the effect of interfering materials, e.g., quenchers, coincidently present in the solution.

With a little ingenuity on the part of the operator, several of the conventionally designed photometers can be adapted to fluorometric work. A number of reviews setting forth the relative merits of different photometers are available.[9] Thus, a simple fluorometer of the Duboscq type has been employed in fluorochemical work.[10] The in-

[9] Cf. W. E. Barrows, *Light, Photometry and Illumination*, New York, McGraw-Hill Book Co., 1912.

[10] W. Koch, *Nature*, **154**, 239 (1944).

strument is illuminated by a 220 volt U-shaped Hanovia quartz mercury arc, and both cups are illuminated from the front by the same light source. This arrangement cancels variations in light output and provides a uniform illumination throughout the cup containing the sample.

There has recently been designed and manufactured an inexpensive and efficient optical fluorescence comparator, which serves for the quantitive fluoranalysis, by means of fluorescent standards, of a variety of substances, e.g., vitamins, quinine, atabrine, drugs, oils, and organic and inorganic compounds.‖ The instrument is of high sensitivity and simple operation, being designed for visual operation. The optical fluorometer makes it possible to carry out the comparing operation without effort or eye strain, despite the fact that the fluorescences of the unknown and known may be very weak. Unlike the electronically operated fluorometers, described subsequently, it is suitable for use under any temperature and humidity condition that may be encountered and can be operated from any power line regardless of voltage and frequency fluctuations.

The presently favored fluorometers are, with the above-mentioned exception, independent of the seeing act, and require either a photographic plate or a sensitive photocell and auxiliary amplifying equipment.

The photography of fluorescent light is designated by the term "fluorography." In past years, several investigators have successfully photographed fluorescing objects in both black-and-white and in color.[3] Since the luminescence is quite feeble by ordinary standards of brightness, it is necessary to employ faster films or plates and/or longer exposure times. Briefly, fluorography is accomplished with an ordinary camera, the lens of which is protected by a filter transparent to visible wavelengths, but opaque to the exciting ultraviolet light beam, i.e., a filter cutting off at about 4000 Å. In a photograph taken by this means, only the emitted light passes into the camera, and portions of an object which absorb ultraviolet, but do not luminesce, have no distinctive appearance on the image-bearing emulsion, as do ultraviolet reflecting surfaces, since the glass or other filter over the camera eliminates scattered and reflected radiation.

As would be expected, the density of the light-struck emulsion depends upon the intensity of the fluorescence. If the conditions of

‖ Manufactured by the Photo-Volt Corporation, 95 Madison Avenue, New York 16, N. Y.

fluorography are standardized, it is possible to determine the fluorescence intensity of the emitter by photometry of the plate or film negative. When care is taken, fluorography provides an enormously delicate means for the detection and determination of fluorescent materials, since very sensitive panchromatic plates and films, e.g., those used in spectrography and astrophysics, are manufactured,[11] such

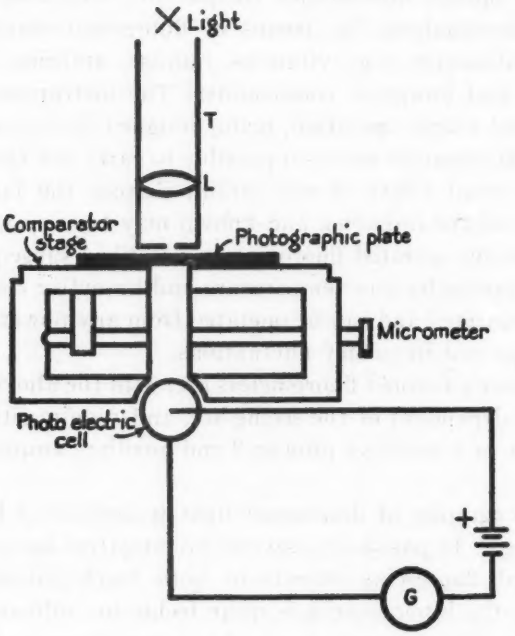

FIG. 3. The Perrine electronic microdensitometer, employing a photocell and galvanometer for precision density readings of photographic plates.

photographic materials being available in a variety of speeds, contrasts, and sensitivities. High speed panchromatic film is generally used for such work. In accurate work, the processing of the film is carried out in the usual fashion and, by the familiar time-temperature method of development, the film is developed to a standard gamma. After processing, the film is then subjected to microdensitometry, preferably employing a delicate photoelectric densitometer.

The fluorographic method of fluorometry has recently been per-

[11] Cf. Eastman Kodak Company, *Photographic Plates for Use in Spectroscopy and Astronomy*, 5th edition, Eastman Kodak Company, Rochester, N. Y., 1943.

fected for the petroleum field by the pioneering work of W. B. Ferguson.[12] The apparatus employed by Ferguson (Fig. 4) is essentially that described above, but the technique has been completely standardized so that it may be integrated with the requirements of the oil field. Ferguson advises a set-up with two General Electric Company S-4 Hg arcs, emitting in the long wavelength ultraviolet, as sources of

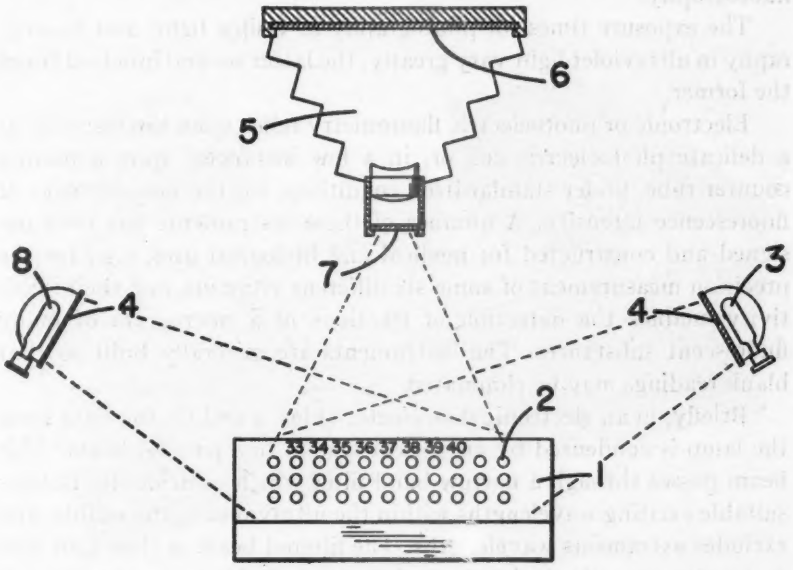

FIG. 4. The apparatus designed and employed by Ferguson for measuring the fluorescence intensities of many soil samples at one time. The holding block 1 supports soil samples 2, which are illuminated by ultraviolet lamps 3 and 8, possessing filters 4 to exclude the visible rays but pass the invisible ultraviolet. The camera 5 is equipped with a filter 7 that excludes the ultraviolet, but passes the visible which is recorded on the photographic plate 6.

excitational energy, Wratten 18A filters for the lamps, a Wratten 2A filter over the camera, and high-speed panchromatic film for the recording. The lamps are placed some 20 in. from the tray holding the samples, and an exposure of the order of two hours with a lens aperture of f:4.5 proves satisfactory for typical soil samples and well cuttings. He states that the exposure time is chosen with relation to the intensities in such a way that the densities lie on the substantially straight portion of the characteristic of the film employed.

[12] W. B. Ferguson, *U. S. Patent 2,356,454*, August 22, 1944.

When Ferguson's method is applied to oil prospecting it is desirable to photograph the samples separately under ultraviolet light and white visible rays, respectively. Ordinarily there is included among the samples a blank, preferably a soil sample or other material known not to be fluorescent. The blank should possess a white light color lying between white and black, lighter than any of the soil samples undergoing fluorography.

The exposure times for photography in visible light, and fluorography in ultraviolet light vary greatly, the latter several hundred times the former.

Electronic or photoelectric fluorometry relies upon the response of a delicate photoelectric cell or, in a few instances, upon a photon counter tube, under standardized conditions, for the measurement of fluorescence intensity. A number of these instruments has been designed and constructed for medical and biological uses, e.g., for the precision measurement of some six different vitamins, and their sensitivity enables the detection of fractions of a microgram of many fluorescent substances. The instruments are generally built so that blank readings may be eliminated.

Briefly, in an electronic fluorometer (Figs. 5 and 6), the light from the lamp is condensed by an optical system to a parallel beam. This beam passes through a narrow band filter which coincidently isolates suitable exciting wavelengths within the ultraviolet or the visible, and excludes extraneous wavelengths. The filtered beam is then split into two parts, one of which enters the sample holder, a cuvet of glass possessing low ultraviolet absorption. The fluorescence is then registered by two large barrier-layer photocells arranged laterally on both sides of the sample holder and connected in parallel. Filters between the sample holder and photocells serve to isolate the specific fluorescence band and to eliminate the influence of exciting light which may be scattered by suspended particles in the liquid sample.

The other part of the beam is deflected by a front surface mirror and acts upon the balance cell mounted so that it can be turned through an angle of 90°. The two measuring photocells and the balance photocell are connected in a bridge circuit with a slide wire and with a galvanometer as the zero indicator.

Other designs of fluorometers are available, but the previously described device is representative of an instrument in wide use today. The first fluorometers employing photocells were intended for vitamin assay, but refinements in construction and operation have resulted

in an instrument of considerable utility and value in many kinds of analytic work.[13–22]

FLUORESCENCE SPECTROPHOTOMETRY

As far as petroleum work is concerned, scant use has thus far been made of fluorescence spectrophotometry. This is aside from the fact that electronic fluorometry may be considered an abridged form of

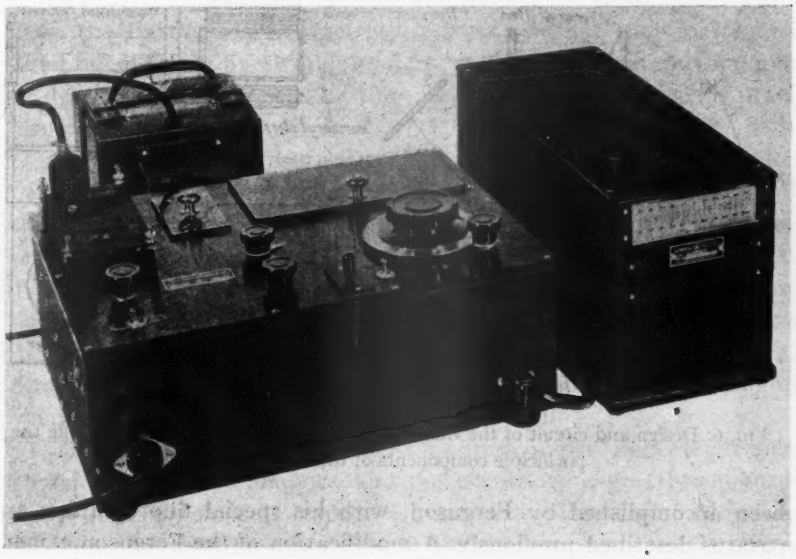

FIG. 5. The Lumetron Photoelectric Fluorometer is representative of a series of instruments in wide use for the detection and determination of fluorescent materials by electronic means. The instrument shown above comprises the fluorometer proper, a stabilized voltage transformer, and a galvanometer.

[13] Cf. D. B. Hand, *Ind. Eng. Chem., Anal. Ed.*, **11**, 306 (1939).
[14] C. E. White, *Ibid.*, **11**, 63 (1939).
[15] F. H. Cohen, *Rec. tray. chim.*, **54**, 133 (1935).
[16] D. S. Hennessey and L. R. Cerecedo, *J. Am. Chem. Soc.*, **61**, 179 (1939).
[17] F. Germann and J. Hensley, *Univ. Colorado Studies, D*, **1**, 37 (1940).
[18] E. Jette and W. West, *Proc. Roy. Soc. London*, **121A**, 299 (1928).
[19] R. Toussaint, *Compt. rend.*, **193**, 933 (1931).
[20] O. S. Duffendack and W. E. Morris, *J. Opt. Soc. Am.*, **32**, 8 (1942).
[21] M. A. Konstantinova-Shlezinger, *Zavodskaya Lab.*, **8**, 957 (1939); *Khim. Zhur*, no. 3, 49 (1940).
[22] J. De Ment, *Fluorescent Chemicals*, 2d edition, vol. 4, *Fluorochemical Analysis*, New York, Chemical Publishing Co., 1946.

spectrophotometry, since narrow band filters are usually employed to select the most intense and characteristic bands in the emission of a fluorescing substance. Fluorescence spectrophotometry, and the various instruments employed in such work, have recently been described by the present writer.[1]

Developments in this branch of the science seem to be forthcoming, and an abridged approach to oil detection and appraisal has

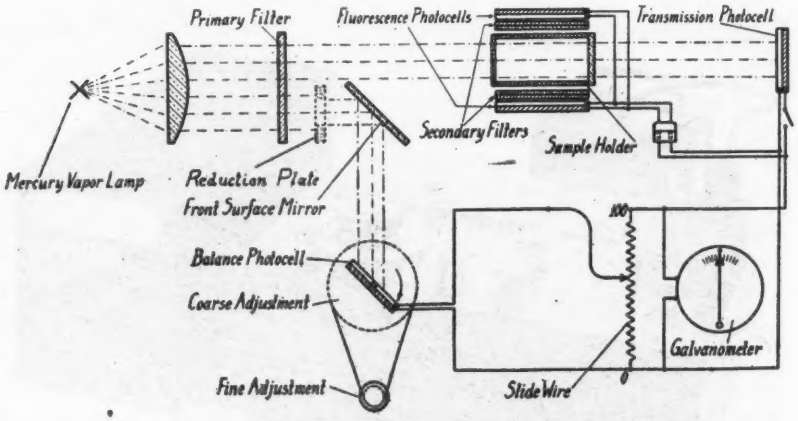

FIG. 6. Design and circuit of the Lumetron electronic fluorometer, illustrating the principle components of the instrument.

been accomplished by Ferguson, with his special fluorographic apparatus described previously. A modification of the Ferguson camera is used when the color of the emitted light is diagnostic, i.e., when superior criteria may be secured by intensity measurements of limited spectral components of the fluorescent light emitted by the sample. In this modification, photographic records are made with two or more filter film combinations having different spectral responses. In many cases, these responses should approximate standard I.C.I. color mixture curves so that the results give the tricolor stimuli for the emitted light. The familiar one-shot cameras, employing half-silvered mirrors, may be used to obtain the exposures simultaneously on separate films, or bipack or tripack films such as Kodachrome, may be used in an ordinary camera as shown in Ferguson's apparatus in Fig. 4.

FLUOROADSORPTION ANALYSIS

The adsorption of fluorescent materials upon an inert, nonfluorescent substrate may serve to enhance their emission. Likewise, adsorption analysis permits the selective isolation of molecules from a com-

plex mixture of substances. In petroleum work adsorption means prove satisfactory, since they allow the appraisal of very small amounts of oil, say extracted from drill core or mud, this being a desideratum in a large part of the fluoroanalysis of petroleum carried at concentrations corresponding to parts per hundreds of million in water, shale, mud, cuttings, earths, and the like.

The fluoroadsorption methods of analysis can be classed as either chromatographic or capillary, depending upon the adsorbant. In both cases the aim is to isolate petroleum traces so that they may be excited to emit light by ultraviolet light, and so that their emission may be detected and measured by the visual and electronic means previously discussed.

When a sorptive substance, such as rough, unsized paper (like filter paper), is moistened at a point with a drop of liquid, the liquid will spread more or less, depending upon such physical factors as the air pressure, degree of saturation of the air, and the particular solvent. When the liquid contains a solute, the extent of spreading of the various constituents will not in general be the same. This results in rings or bands, depending upon whether or not the liquid spreads in all directions, or in one direction, as in the case of a strip of paper hanging vertically with one end immersed in the liquid.

This phenomenon lays the basis for an extremely delicate physicochemical method of analysis, and the sensitivity is greatly enhanced if the capillary strip is inspected under ultraviolet light. Molecules which ordinarily do not fluoresce in the condensed phase, e.g., liquid or solid state, may often show bright luminescence when dispersed by adsorption. This fact underlying fluoroadsorption possesses a theoretical grounding which is analogous to the concept of concentration quenching.[1] Moreover, substances which are colorless or white to the unaided eye may be distinguished under the lamp.

While the pioneer work on ordinary capillary analysis was done in 1829 by Schonbein, it remained for one of his students, Goppelroeder, just prior to 1901, to apply fluorochemical analysis to this technique. Important contributions to the field have been made by a number of investigators, among whom are Meunier and Bonnet,[23] and Neugebauer.[24] However, the best recent summary of the field, which should be referred to by all who intend to study the applicability of fluoroadsorption methods to petroleum, is that of Germann.[25]

[23] L. Meunier and A. Bonnet, *Compt. rend.*, **180**, 2038 (1925).

[24] H. Neugebauer, *Die Kapillar-Lumineszenzanalyse*, Leipzig, W. Schwabe, 1933.

[25] F. Germann, *Univ. Colorado Studies*, D, 1–14 (1940).

A representative procedure in the use of paper strips is that of Danckwortt and Pfau (cited by Neugebauer[24]), who applied it with great success in a variety of problems. It is requisite that a standard procedure be followed, these empirical approaches often holding for other methods of fluoroanalysis. The paper should be non-fluorescent, cut into strips 2×30 cm, all in the same direction of the grain. The paper strip is then clamped by its top edge so that it hangs vertically, 5 mm of the lower edge being immersed into the solution. Such an arrangement, within a glass tube, may be left for 24 hours in order to assure a state of equilibrium. All conditions must be closely standardized if comparable results are to be secured. The papers obtained with unknowns are compared with samples of known concentration and composition or source, in the case of petroleum work.

For petroleum samples, an ether solution is generally preferred. With such a solution there is a characteristic series of fluorescent zones, and the fluorescence intensities of these are plotted by an electronic fluorometer against the length of the strip. The direct vision fluorometer, especially devised by Germann and Henesly, is excellent for this work. Rojahn and Heinrici[26] have originated a color and luminescence comparator, suitable for capillary work, with which they could reconstruct at any time in the field of the instrument any color by means of three numerical values, namely, ground color, black content and white content. The apparatus is based on the Ostwald color system.

The chromatographic method is very similar to that of capillary analysis, except that a solid column of adsorbant is employed, and the solution is drawn by suction through it. There is an abundant literature on chromatographic analysis, and the application of the lamp to the study of the columns is erroneously termed "ultrachromatography."[27] A non-fluorescent solvent is used, preferably ether, benzene, chloroform, and the like. Thus Mukherjee and Indra[28] separated various crude oils in fractions by adsorption upon a column of aluminum oxide, followed by elution with different solvents. They obtained a qualitative differentiation of the crudes by observing the fluorescence colors of the different fractions in chloroform solution, and the differ-

[26] C. Rojahn et al., *Beiträge zur pharmazeutischen Analyse*, **5**, Halle, Akademischer Verlag, 1937.

[27] Cf. H. H. Strain, *Chromatographic Adsorption Analysis*, New York, Interscience Pub., 1942.

[28] J. N. Mukherjee and M. K. Indra, *Nature*, **154**, 734–745 (1944); *J. Inst. Petroleum*, **31**, 173–178 (1945).

ences in color between the main bulk of the solutions. The capillary strip method was also employed with satisfactory results, in order to distinguish between crudes of different origins, e.g., crude and refined oils from Digboi and Assam, some artificial crudes, and a chloroform extract of a resin.

These workers employed a quencher, nitrobenzene, to measure the fluorescence, and by this method the intensity appeared to have some value for distinguishing the oils, through a combination of spot tests and capillary analysis on paper strips easily and rapidly yielded distinctions among the particular varieties of oil used.

FLUORESCENCE MICROSCOPY

The fluorescence microscope is merely an instrument which allows a microscopic examination of an object under the influence of filtered ultraviolet light.[29–30] The optics of such a microscope should, of course, be commensurate with the radiation being employed, and should be non-fluorescent and transparent to ultraviolet rays. This latter factor need not be true for the optical system within the body tube of the microscope itself, since only the fluorescence is under inspection. As in bright field microscopy, fluorescence microscopy may be either of the transmitted or reflected variety. The latter is used on opaque specimens, and both types of work can be accomplished with an ordinary microscope which has been slightly modified insofar as its illuminating system is concerned. This can be achieved with a little ingenuity on the part of the microscopist, though a number of optics manufacturers have special instruments available for the specific purpose of fluorescence work.*

Since petrographic methods play an important role in geophysical exploration, it may be expected that an attractive future lies ahead for the utilization of the fluorescence microscope as an auxiliary tool. This is to state that features of petrographic sections, which may not be evident in bright field work, are often quite easily seen and appreciated under ultraviolet light by their fluorescences.

However, the fluorescence microscope enables the detection of

[29] Cf. M. Haitinger, *Die Fluoreszenz analyse in der Mikrochemie*, Wien und Leipzig, Emil Haim, 1937.

[30] J. Radley and J. Grant, *Fluorescence Analysis in Ultra-Violet Light*, 3d. edition, New York, D. Van Nostrand Co., 1939.

* Fluorescence Microscopes are available in this country from the American Optical Company, Spencer Lens Division, Buffalo, New York, and from the Bausch and Lomb Optical Company, Rochester, New York.

trace fluorescences in drill cores, earths, mud, cuttings, and the water residues prepared by careful evaporation. Actually, however, little use has been made of the fluorescence microscope in fluorochemical prospecting, either in the petroleum field or in sundry, related branches of mineralogy and geology. One paper on the subject has dealt with the examination of drill cores, and the features of the analytic methods described therein can effectively be adapted to fluorescence microscopy.[31]

The fluorescence microscope is truly of wide utility and value, and its advantages are of increasing importance in a large number of branches of the arts, sciences, and industries. Hence, it should not be minimized as a research instrument for petroleum fluorochemistry studies. The florescence microscope may be fitted with a spectroscopic eye-piece for a determination of the spectral nature of the light emitted by an object under scrutiny.[32]

PETROLEUM FLUOROCHEMISTRY

Under filtered ultraviolet light, crude oils generally exhibit a blue, blue-green, or greenish fluorescence. This is usually admitted to be the most prevalent emission hue, but considerable deviation may occur in oils from different localities. The fluoroescence of crude petroleum is excited by ultraviolet light of wavelengths down to 2000 Å, though the so-called "near ultraviolet," that approximating 3650 Å, is recognized as creating a brighter response in this substance. The source of ultraviolet light which releases a preponderance of long wavelengths is often chosen for prospecting in the field, and also for more refined studies in the laboratory. However, there are certain advantages in use of the quartz mercury arc, which releases much of its light at 2537 Å, almost coinciding with two absorption maxima, i.e., the two lying at 2420 and 2650 Å, in that region of the spectrum. Such light can be employed efficaciously for sands, shales, drillings, and cores, not only to detect petroleum, but also to reveal the presence of other formations or for detecting economically important mineral species which do not respond to the longer wavelengths.[33]

As an activator in solids, little can be said about the role petroelum plays. It is known that fluorescence occurs in friable earths and various

[31] J. De Ment, *Oil Weekly*, **103**, 17–19 (1941).

[32] J. De Ment, *Trans. Am. Microscopical Soc.*, **61**, 306 (1942).

[33] J. De Ment, *Bull. Ultra-Violet Prod., Inc., No. 2*, 1 (1944); *Oil and Gas J.*, **44**, 75–80 (1945).

rocks containing traces of petroleum, but scant theoretical work has so far been performed. Traces of petroleum may not infrequently be found disseminated throughout a crystalline mineral, producing a brilliant and characteristic fluorescence.[1,3] Texas localities yield large crystals of calcite containing oil, which gives rise to a fluorescence independent of manganese activation, and it has been suggested that the group of calcites which show a greenish fluorescence may contain a hydrocarbon impurity.[34]

Oil shales have been studied under the lamp, and interesting results have been produced. Radley and Grant[4] state that common shales ("Blaes") appear a very dark brown in the massive state, while the color may be absent in the powdered form. With a kerogen shale, a rich chocolate brown was observed in both the powdered and the lump forms. Torbanite and cannel can be distinguished readily by their fluorescence, since the former shows bright yellow streaks on a brown background. Wittich[35] has studied Esthonian and Manchurian shale oils, and has found that useful indications can be obtained as to their origin, preparation and process of cleaning, and that individual fractions can be graded according to their boiling points from the fluorescence.

In the study of oil shales, the fluorescence microscope offers an entire new field of investigation for the petrographer.

There is a good deal of information available on the fluorochemistry of materials related to petroleum. Thus, bitumens, asphalts, coal tars, and the like, not only fluoresce, but do so in great dilutions. The origin of such materials can be empirically identified by the response,[36] and a trace of coal-tar pitch, as an example, shows in asphalt by its greenish-blue emission when present at 1:50,000.

Petroleum oils and certain refined products, e.g., petrolatum, fluoresce at great dilutions in various liquid solvents. The solvents which are usually employed include: benzene, hexane, ethyl ether, carbon tetrachloride, chloroform, various liquid straight chain hydrocarbons, and similar substances.

The threshold of detection varies of course according to the method employed. For unaided eye observation, 1 part oil in 100,000 parts carbon tetrachloride, can be seen easily. If the eye is supplanted by

[34] H. C. Dake and J. De Ment, *Fluorescent Light and its Applications*, New York, Chemical Publishing Co., 1941, pp. 123–125.

[35] M. Wittich, *Brennstoff-Chem.*, 1927, No. 19.

[36] W. Teuscher, *Chem. Fabrik*, **53** (1930); **54** 397 (1930).

an electronic fluorometer, or by photographic methods, the dilution may range to the order of parts per hundreds of millions. Heavy oils can be detected at a dilution of one part in 500,000 to 200,000 parts of water, and gasoline only at 1:20,000 for the same solvent.[37] Dispersed in soils, oil concentrations corresponding to a few parts in tens to hundreds of millions can be detected with photographic apparatus, e.g., that of Ferguson.

SPECIALTY METHODS IN EXPLORATION

In 1936, John Melhase[38] first described, in a classic paper of some 450 words length, the values of fluorescence and ultraviolet light as an aid in correlating oil sands. Since the publication of this paper, the applications of ultraviolet light to petroleum exploration and technology have increased greatly, and every suggestion given in the original article has proven out in practice.[39]

It is rather astonishing to read the original paper and to appreciate how fundamental the studies of Melhase were. He states: "During the past two years the writer (Melhase) has tested oils from many of the California fields and from different sands that may occur in these fields and it was found that no two samples of oil exhibited the same quality and degree of fluorescence unless they were obtained from identical sands. . . . It follows, therefore, that when a well is drilled in any particular field and samples from each of the various sands penetrated are tested and classified according to their respective fluorescent qualities, the record thus obtained becomes an index for that field. When subsequent wells are drilled the new samples may be compared with the index and correlated accordingly. It is necessary, of course, that the samples to be tested consist of oil or of sands containing oil. Neither the gravity of the oil nor the percentage of mud and water in the sample has any effect upon its fluorescent properties and it matters not how the sample is secured, whether from the ditch, bailings, or extracted from the core if the formations are cored."

Further: "It is possible that expensive core-drilling may be entirely eliminated by this method, thereby saving millions of dollars to the oil industry. At any rate, correlation of oil sands by means of fluorescence is simple, quick, and positive, requires no expensive nor elaborate equipment, and anyone possessing normal eyesight is capable of

[37] J. Halstrick, *Arch. Hyg. Bakt.*, 128, 155–168 (1942).
[38] J. Melhase, *Mineralogist*, 4, no. 2, 9 (1936); reprinted, *Ibid.*, 7, 166 (1939).
[39] J. De Ment, *Mineralogist*, 13, 425–427 (1945).

making the necessary comparisons and tests . . . if a series of oils is classified under a mercury arc lamp it is essential that the same type of lamp be used when making comparisons or correlations upon samples of unknown origin."

The preliminary work of Melhase has given way to more accurate and standardized, though generally empirical, laboratory and field methods. The correlations are not limited to shales, but also include any earth bearing petroleum, either of surface or of subsurface origin, e.g., muds, water, drill core, or definite rock and mineral species secured with or without drilling. In the case of drill cores and cuttings, the fluorescence enables the detection of a body of oil ahead of the bit, as will be discussed in more detail subsequently.

The method, however, is neither fool-proof nor perfectly reliable. As the techniques are often empirical, developed in the laboratory according to the bents of the technician, there may be considerable latitude in the extent of dependability of results. The inspection of untreated earths with the unaided eye is open to much more error than the study of these materials either with instrumental techniques or by extraction and subsequent objective measurement. Trace amounts of highly fluorescent minerals, such as scheelite or secondary uranium minerals, may negate results for an inexperienced observer. Likewise, emphasis should be placed upon the possible untoward effects of air on the sample, since many cores, after aging and exposure to subtropical climate, may lose their fluorescence. The role of hydrocarbon-oxidizing bacteria in the destruction of oil traces in rock or earth should not be discounted.

Bates[40] has found that well cores and cuttings, even when small, broken, or partly contaminated, react very positively if they contain liquid hydrocarbons. He finds diagnostic criteria in the intensity of fluorescence and in the distribution of fluorescence throughout the sample, though he doubts that wide variations in color can be detected. Bates has observed that oil up to about 45° A.P.I. (corr.) shows a brilliant white light under the cold quartz mercury arc, and that high gravity oil or colored distillate between 45° and 55° gravity shows a fair fluorescence. In general it is found that a producible sand will give uniform fluorescence throughout, while a sand carrying salt water in addition to oil will exhibit a mottled or blotched fluorescence. In local

[40] F. W. Bates, Communication to T. S. Warren, March 7, 1945. The fluorochemistry of petroleum distillates has been described by Brooks and Bacon, *Ind. Eng. Chem.*, 6, 623 (1914).

areas increases in oil saturation and productivity seem to increase intensity.

Bates adds, significantly, that to a considerable degree the applicability of the technique depends on the individual interpretation, skill, and range of experience of the analyst. He has found that the cold-quartz mercury arc, emitting most of its light at 2537 Å, is particularly useful for quick evaluation of the small side-wall core samples which are often taken in great numbers. In several instances this has indicated the prospective value of sands subsequently proven productive that might otherwise have been overlooked. When properly handled the Bates recommendations disclose the presence of oil undetectable by odor, taste, stain, saturation analyses or electrical log.

The experience of the writer[33] leads him to favor solvent extraction methods in the unaided eye study of cores and cuttings. There are numerous variations possible in the procedure that may be followed, but he has found that solvent extraction not only increases the delicacy of the method but serves to minimize the effect of interfering factors. A representative and easily manipulated procedure, developed in the laboratory of the present writer, follows:

(a) *Prospecting.* The sample as obtained is placed under ultraviolet light in darkness and the fluorescence, if any, observed with the unaided eye. Best observations are made by viewing the sample at right angles to the lamp and after the eye has allowed itself to be adjusted to night-vision by remaining in the darkness for some minutes beforehand. The mud, drillings, sand, or other specimen is placed in a dish or test-tube which does not fluoresce, alongside a similar vessel containing a dozen or so drops of known-fluorescent petroleum in carbon tetrachloride. The two are inspected simultaneously. If the sample consists for the greater part of water or of mud and water, it is advised that a wide-mouth vessel, like a non-fluorescent metal pan or bowl, be used. In this case the sample is allowed to set for several hours or over-night before the examination is made. If oil is present, droplets will rise to the surface and form a thin film or appear as droplets, and these can be seen under ultraviolet light. When using a wide-mouth bowl a comparison sample is viewed alongside the unknown. This comparison sample is prepared by dropping a few drops of petroleum onto the surface of water or mud which does not fluoresce. Pyrex dishes can also be used in this method, but they should be placed upon a sheet of black, non-fluorescent paper or cloth.

The preceding method is representative of the most elementary and cursory of the tests available. One should practice with known

samples having different amounts of oil present so that the fluorescence in an unknown can be recognized. The above method is also of somewhat restricted sensitivity: where the fullest appreciation of a test is desired the following technique can be employed.

The sample of mud or water as obtained is thoroughly shaken with carbon tetrachloride, using about equal volumes of each, and the two allowed to separate by setting for a short time. The carbon tetrachloride, which takes up any oil present, is then carefully separated from the remaining material and filtered through medium or fine grade paper. This is done to eliminate extraneous matter which may have passed along with the carbon tetrachloride when it was separated from the sample: also, it will give an indication of whether or not the sample and solvent have been allowed to set long enough for separation. If the filter paper shows wet spots, particularly near the cone, after it has been freed of carbon tetrachloride by standing in the air for a few minutes, one can assume that there is water present in the extract and that the separation of water and solvent has not been complete. Small amounts of water carried along with the solvent (which contains the oil) may impart a bluish fluorescence which might be mistaken for a low concentration of oil. Also, great care must be taken to obtain carbon tetrachloride which is completely void of any fluorescence: many commercial grades of this solvent have a slight blue luminescence and this, added to the blue and purple light passed by the filter on the lamp, may give false results.

To get an idea as to how much petroleum may be in a given sample, extracted by the above method, the ultraviolet examination is made by using standards containing known concentrations of crude oil in carbon tetrachloride. The standards can be made up arbitrarily, by adding successively, 1, 2, 3, 4, . . . drops of oil to 15–20 cc of solvent and diluting out if lower concentrations are desired. It is convenient to make up standards in two sets of 15 each. One set is kept in the darkness as a reference series and the other is used in the actual comparison, though in use excessive exposure to the lamp is avoided. Depending upon the oil concentrations of the samples being worked with, different values of concentration are given each item in the series. For general purposes the sets can have known oil concentrations corresponding to 0.5, 1, 2, 4, 6, 8, 10, 12, 18, 24, 30, 34, 40, 60, and 80 parts per million. One drop of oil is about 0.05 cc. Other concentration ranges can be made up as desired. A stock solution of 100 or more p.p.m. can be made up in larger amounts from which to prepare subsequent standards.

The standards are kept in 10 or 20 cc non-fluorescent glass bottles. New cork stoppers are used, but not rubber stoppers, for rubber contains fluorescent materials which dissolve off into the carbon tetrachloride. When not in use they are protected from the light. All bottles must be of the same size and shape, and the unknown is viewed in a similar bottle alongside the standard.

(b) *Correlating.* In quantitative work the previous extraction method is employed, except that care is taken to weigh the sample and measure the volume of solvent used to extract the sample. When the fluorescence is feeble or questionable, part of the solvent is allowed to evaporate off, so raising the concentration of any oil that it may contain. Just prior to the inspection, however, the remainder of the extract must be measured and computations based on the total.

The comparison method, using an oil extract, should be well practised in the laboratory before starting on unknowns if correlations are to be made at a later time. For prospecting it is not as important to follow the rules closely, for the criterion is merely the fluorescence and its approximate brightness and color. In obtaining a representative value of the oil present several samples, up to six or more, should be taken from the same locality, or at least until approximately reproducible results have been obtained. The method is likewise applied to other localities or areas which are to be correlated.

The amount of oil can be expressed in several ways, as parts per million, in percent, or by arbitrary fluorescence standards. None appears to have any particular advantage over the other, with perhaps the exception of the latter.

FLUOROLOGGING

Well log curves prepared from fluorochemical data yield more extensive and reliable information than random studies.[41] Such curves are called "fluorologs," and the data are secured from cuttings and core samples as ordinarily taken for paleontologic analyses. Core samples are not necessary in the procedure, which has been developed by Ferguson, but it is desirable to have samples of all cores taken. Generally, the cuttings samples are taken at an interval of not more than 30 feet, but samples taken at shorter intervals provide more accurate results. The sampling is begun at the surface and continued at regular intervals to the total depth of the hole.

[41] W. B. Ferguson and O. E. Campbell, *The Fluorographic Method of Petroleum Exploration*, 10 page brochure, Houston, Texas, Fluorographic Exploration Company, April 24, 1945.

The assay is made with the Ferguson photographic apparatus, previously described and shown in Fig. 4, and the fluorescence intensities are plotted against depth. It is not necessary, however, to depend

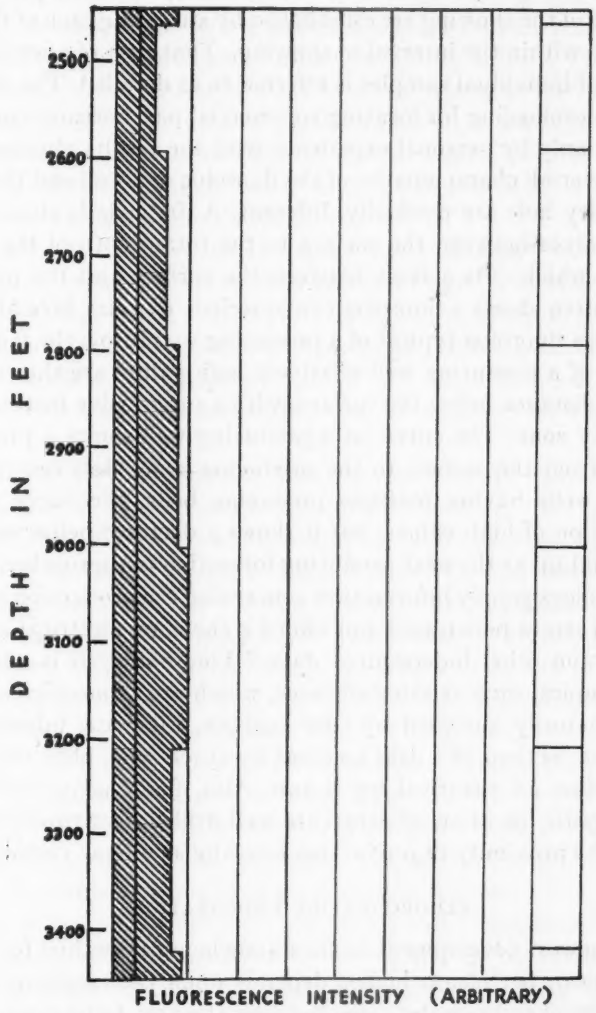

FIG. 7. A section from the fluorolog, illustrating the manner in which fluorescence intensity is plotted against the depth at which the sample was obtained.

wholly upon photographic procedure, since the aim is to detect and measure fluorescences of a very low order-of-brightness.

In practice, a log (Fig. 7) is prepared from composite samples,

which are obtained by mixing proportional amounts of the samples from two hundred feet of hole. If the fluorescence density of a composite sample runs above a given value, a possible pay sand is indicated somewhere in the interval covered by the sample. The depth and the true value of the showing are established by analyzing each of the samples taken within the interval of showing. That part of a log based on analyses of individual samples is referred to as detailed. The effectiveness of fluorologging for locating commercial pay horizons can be appreciated only by personal experience with the results obtained.

The over-all characteristics of the fluorolog of a well and the fluorolog of a dry hole are markedly different. A dry hole is characterized by low values between the surface to the total depth of the hole. A producer which cuts a fault between the surface and the producing horizon often shows a fluorolog characteristic of a dry hole above the fault, but a fluorolog typical of a producing well below the fault. On a fluorolog of a producing well relatively high values are shown at and for some distance below the surface, with a progressive increase down to the pay zone. The curve on a producing well shows a progressive increase from the surface to the producing zone. Between pay horizons, in wells having multiple producing beds, the curve shows a continuation of high values, but it shows a decrease below each sand and a build-up as the next producing formation is approached.

Fluorologs supply information concerning the production possibilities of all strata penetrated and afford a check on electrical logs, core analyses and other independent data.[42] Fluoroanalysis is adapted to small samples, such as sidewall cores, which are of insufficient size to be satisfactorily analyzed by core analysis. Likewise, information is secured on sections of a drill hole lost by stuck pipe, blow-out, and so forth, before an electrical log is run. Also, fluoranalysis will give a characteristic log of an off-structure well drilled near production and predict the proximity of production laterally as well as vertically.

FLUOROGRAPHIC EXPLORATION

The newest development in the fluorochemical method for locating subterranean petroleum bodies depends upon the response to ultraviolet light of soil samples collected over the area to be explored. The analysis of soil samples, and the interpretation of data secured there-

[42] W. B. Ferguson, Personal Communication, December 13, 1945.

from, is known as "fluorographic exploration," a technique developed several years prior to 1943 by Blau.[43]

In fluorographic reconnaissance field work, soil samples are taken at stations one-quarter mile apart on a regular grid pattern. A reconnaissance survey is sufficient for most projects, since it will establish approximately the outline of a favorable prospect, as well as develop considerable detail. If greater detail is desired, the samples may be taken at intervals of one-eighth or one-sixteenth mile. A minimum area of twenty-five square miles should be covered in a survey, so that anomalies can be established.

Equally satisfactory results have been obtained from samples taken in all types of terrain, ranging from swamps to sand dunes, in all parts of Texas, and in parts of Louisiana, Mississippi, Kansas and New Mexico. Soil samples taken at the same stations at different times and under different conditions exhibit the same fluorescent characteristics, so a fluorographic survey can be repeated with equivalent results

The Blau method depends upon the fluorescence characteristic of petroleum or its derivatives, as previously described, the employment of soil standards of known concentration, and the empirical correlation of soil samples with the locality from which they were obtained. At the present time, the Ferguson fluorophotographic apparatus is relied upon for measurement of the fluorescence characteristic of the soil samples, and the interpretation is performed by an oil geologist.

The novel feature of the newer means of oil exploration lies in the fact that drilling is unnecessary. The soil samples are collected to a depth of within several inches of the surface. Plant material is carefully excluded by scraping away such debris as might contaminate the specimen, since many roots and leaves contain fluorescent substances which would render the fluorochemical examination invalid. In a given region, all samples are obtained from uniform depths.

The soil samples as obtained are placed under ultraviolet light and the intensity of the fluorescence determined by comparison with standards prepared from non-fluorescent soil and crude oil. In the preparation of standards, the crude oil is dispersed throughout the soil carrier by carbon tetrachloride or other solvent in which it is first dissolved. The standards are made up so as to contain 10, 20, 30, 40,

[43] L. W. Blau, *U. S. Patent, 2,337,443*, December 21, 1943.

50 . . . parts of oil per million of soil. For samples containing large amounts of oil, or when only semi-quantitative data are desired, visual comparison in an inspection cabinet often serves satisfactorily.

A fluorographic survey is interpreted by posting the fluorescence intensity values on the survey grid according to the location from which they were taken, and contour lines, called "isofluors," are drawn to correspond to the fluorescence values of the stations. A subsurface accumulation of petroleum will show an isofluoric enclosure. If structure is present, an isofluor map will disclose the geological pattern of that structure. The isofluor map is particularly effective for locating faults and minor geological features, and the details will enable a geologist to differentiate between a structural and a stratigraphic accumulation. The more detailed isofluor maps are prepared by using individual station values as control points, and any degree of generalization may be accomplished by drawing isofluors on control points obtained by averaging station values in groups of four, nine, sixteen, and so forth.

The final interpretation or recommendation is empirical, and valid data are secured only after the study of a series of maps embracing both the most detailed and the most generalized of information.

The working theory of fluorography has arisen entirely by the trial and error method, so faulty results that may be obtained in its use will not be due to discrepancies in the theoretical grounding of the technique, but in the large personal equation which may enter into an interpretation of the results. Thus, the value of the fluorographic method depends to a large extent upon the personal skill and experience of the analyst. However, the facts established by fluorescence data indicate that there is a genetic relationship between a subsurface petroleum reservoir and the fluorescence characteristic of the surface soil above the reservoir.

This implied genetic relationship between a petroleum accumulation and the overlying earth is also indicated by the fact that the fluorescence of samples taken from a well drilled into an oil bearing formation, increases in intensity as the source of the samples approaches the petroleum deposit, attaining maximum fluorescence in the oil bearing rock.

PATENTS*

GEOCHEMICAL PROSPECTING

U. S. No. 2,403,002. H. L. Johnson. Iss. 7/2/46. App. 3/6/40.

Apparatus for Undisturbed Overburden Sampling. A soil sampler having a double core barrel the outer one making an annular cut and the inner one picking up the core.

U. S. No. 2,403,631. C. B. Brown. Iss. 7/9/46. App. 7/5/43.

Method for Determining the Petroleum Hydrocarbon Content of Earth Samples. A method of analyzing soil samples by dissolving out hydrocarbons with a non-fluorescent solvent and observing the intensity of fluorescence when the solution is subjected to filtered light of various spectral bands and comparing with an empirical chart.

U. S. No. 2,406,611. H. T. Kennedy. Iss. 8/27/46. App. 7/3/40. Assign. Gulf Research & Development Co.

Geochemical Prospecting Method. A method of geochemical prospecting in which soil free ground water samples are taken at levels close to the water table, promptly sealed from contact with air and analysed for traces of ethane.

MAGNETIC PROSPECTING

U. S. No. 2,403,347. M. C. Depp and C. F. Fragola. Iss. 7/2/46. App. 4/15/43. Assign Sperry Gyroscope Co., Inc.

Flux Valve. A flux valve which has an adjustable magnetic shunt projecting from the core near the middle of the pick-up coil, adjustment being made to balance out any signal due to direct linkage with the exciting circuit.

U. S. No. 2,403,669. E. J. Martin and C. E. Grinstead. Iss. 7/9/46. App. 4/20/44. Assign. General Motors Corp.

Inductor Compass. A flux valve excited by a square wave obtained by interrupting d-c and in which only the signal induced on the make is impressed on output thyratrons by the use of commutators synchronized with the interrupter.

U. S. No. 2,404,806. H. A. D. Lindsey, U.S.A. Iss. 7/30/46. App. 3/19/42 and 3/29/43

Submarine Detector. An airborne submarine detector to be towed by a plane and having crossed cores with pick-up coils connected to an amplifier and indicating the presence of a variable field due to motors in the submarine.

U. S. No. 2,406,870. V. V. Vacquier. Iss. 9/3/46. App. 7/21/41. Assign. Gulf Research & Development Co.

Apparatus for Responding to Magnetic Fields. A flux-valve magnetometer in which high sensitivity is attained by using thin cores of high permeability material which reach saturation suddenly and induce high peaks in the secondary winding.

U. S. No. 2,407,202. V. V. Vacquier. Iss. 9/3/46. App. 7/21/41 and 7/17/45. Assign. Gulf Research & Development Co.

Apparatus for Responding to Magnetic Fields. A flux-valve magnetic gradiometer in

* Abstracts by O. F. Ritzmann, Gulf Oil Corporation Patent Department.

which high sensitivity is attained by using thin cores of high permeability material which reach saturation suddenly and induce high peaks in opposed secondary windings.

SEISMOGRAPH PROSPECTING

U. S. No. 2,403,386. B. L. Lubelsky and W. R. Walburn. Iss. 7/2/46. App. 1/30/41. Assign. Heitzman Safety Blasting Plug Corp.

Blasting Plug. A tamping plug made of crimped paper and cardboard and which may be expanded against the wall of the shot hole by a tapered expander.

U. S. No. 2,403,488. T. F. Bennett. Iss. 7/9/46. App. 5/1/45. Assign. Hercules Powder Co.

Explosive Cartridge Assembly. An explosive column assembly using internally threaded sleeves to connect the cartridges and with two threads on the cartridge, one of which engages the thread in the sleeve and the other producing frictional resistance to prevent unscrewing.

U. S. No. 2,403,839. N. W. Adolph. Iss. 7/9/46. App. 5/19/43. Assign. Illinois Powder Manufacturing Co.

Coupling. A coupling for explosive cartridges made of a barbed sleeve with tapered flanges along a longitudinal joint and a tapered locking member which slips over the flanges.

U. S. No. 2,407,442. J. O. Parr, Jr. Iss. 9/10/46. App. 1/29/43. Assign. Olive S. Petty

Separation of Blasting Circuit Leads. A cap line severing device to be used at the top of shot hole casing and having a hinged cover over the casing which shears off the wires when the hole blows out so as to eliminate danger due to contact of cap wires with high tension lines.

U. S. No. 2,407,605. J. V. Hammond and D. J. Keenan. Iss. 9/10/46. App. 3/12/45. Assign. J. V. Hammond.

Blasting Unit and Short-Circuiting Device. A battery type shot firing device in which the cap wires are connected to a connector plug having short circuited prongs so arranged that when the connector is plugged into the battery unit the short circuit is opened.

U. S. No. 2,408,001. E. J. Shimek and W. B. Hemphill. Iss. 9/24/46. App. 4/14/45. Assign. Socony-Vacuum Oil Co., Inc.

Gain-Control System for Seismic Amplifiers. A combined time-gain control and true avc in which the latter operates about an amplification whose value is determined by the time-gain control.

U. S. No. 2,408,124. H. J. Rolfes. Iss. 9/24/46. App. 9/11/41 and 8/18/42.

Means for Safeguarding Electric Igniters of Blasting Detonators against Accidental Firing. An electric blasting cap with a metal shell and having in its plug a mass of powdered semi-conducting material which grounds static discharge to the shell through coherer action.

U. S. No. 2,408,125. H. J. Rolfes. Iss. 9/24/46. App. 9/11/41 and 8/18/42.

Means of Safeguarding Electric Igniters of Blasting Detonators against Accidental Firing. An electric blasting cap with a metal shell and with sharp projections on the sides of the lead wires adjacent to but not touching the shell so that static discharges will be grounded.

U. S. No. 2,408,189. A. W. Baker. Iss. 9/24/46. App. 11/10/42. Assign. Hercules Powder Co.

Waterproof Explosive Cartridge. A rigid laminated waterproof paper package for water soluble explosives sealed at the ends with a disk and sealing compound.

WELL LOGGING AND SURVEYING

U. S. No. 2,404,132. J. T. Hayward. Iss. 7/16/46. App. 3/15/41.

Apparatus for Use in Logging Wells. An apparatus for logging the volumetric capacity of a well by driving a chart longitudinally with depth and making transverse lines for a predetermined volume of mud or number of pump strokes.

U. S. No. 2,404,622. R. L. Doan. Iss. 7/23/46. App. 3/10/42. Assign. Phillips Petroleum Co.

Well Logging Apparatus. A self contained wire line operated four electrode well logging unit using photographic recording and identifying depth by putting time marks on the record and having a tapered insulated plug where the electrode leads come through the instrument case.

U. S. No. 2,404,825. L. E. Brown and O. W. Williams. Iss. 7/30/46. App. 8/30/41.

Well Tester. Apparatus for sampling side wall formation fluid having a packer in the drill string, the packer being expanded hydraulically after lowering a valve closure on a wire line, the wire line also carrying a sampling chamber which connects to the formation through tubes leading to perforations in the packer.

U. S. No. 2,405,717. C. H. Schadel. Iss. 8/13/46. App. 11/23/42. Assign. Eastman Oil Well Survey Corp.

Orienting Apparatus. An indicating apparatus for orienting a whipstock in a hole of known deviation and which has a ball running to the low side of an annular race and a soft impression disk, the apparatus being retrievable with a wire line through the drill pipe.

U. S. No. 2,405,937. A. H. Beal. Iss. 8/20/46. App. 8/21/44.

Deviation Recording Device. A single shot deviation recorder having a time clock which drives a pointed pendulum down on to a record disk and then depresses the disk on to an inverted index of a second pendulum so as to mark both sides of the record disk.

U. S. No. 2,408,012. P. S. Williams. Iss. 9/24/46. App. 8/10/42. Assign. Standard Oil Development Co.

Well Logging. Well logging apparatus in which a spiked wheel delivers impacts to the formation and the vibrations are picked up by a microphone and high frequency components amplified and recorded.

U. S. No. 2,408,029. C. B. Bazzoni and J. W. Millington. Iss. 9/24/46. App. 7/6/40. Assign. Sperry-Sun Well Surveying Co.

Electrical Prospecting Apparatus. An inductive electrical well logging apparatus in which the exploring coil is excited at two frequencies whose intensities are separately determined by wave meters and recorded.

MISCELLANEOUS

U. S. No. 2,402,965. C. S. Hornberger. Iss. 7/2/46. App. 9/19/41. Assign. Central Scientific Co.

Timing Device. A device for controlling an aerial photographic camera to take pictures at regular adjustable intervals and to start a new sequence of pictures whenever the operator interrupts the regular sequence.

U. S. No. 2,402,985. W. K. Caughey and K. D. Swartzel. Iss. 7/2/46. App. 7/7/42. Assign. Bell Telephone Laboratories, Inc.

Magnetic Recorder. A magnetic tape recorder in which a microphone diaphragm mechanically moves an armature in a magnetic bridge also having in its circuit the pole pieces between which the tape is drawn.

U. S. No. 2,403,152. H. C. Roters. Iss. 7/2/46. App. 11/2/42. Assign. Fairchild Camera and Instrument Corp.

Electrical Position Indicating System. An airplane position indicator which gives direct readings of latitude and longitude by generating a primary a-c, forming two secondary components whose phase depends on the direction of travel and integrating them in proportion to the speed and phase with respect to the primary a-c.

U. S. No. 2,403,424. T. Zuschlag. Iss. 7/2/46. App. 11/1/43. Assign. Magnetic Analysis Corp.

Demagnetizing Apparatus. Apparatus for demagnetizing iron bars and tubes and having primary and secondary coils through which the bar is passed, the primary coil being excited with a-c and the secondary having its current rectified by a grid controlled tube so that the d-c demagnetizes the bar.

U. S. No. 2,403,429. E. I. Anderson. Iss. 7/9/46. App. 11/2/42. Assign. Radio Corp. of America.

Radio Beacon System. A radio beacon navigating system in which two ground stations equidistant from the line of approach send out simultaneous pulses which are slightly ahead of a pulse sent out from the destination station, coincidence of the signals indicating arrival at the destination.

U. S. No. 2,403,472. J. N. Anderson. Iss. 7/9/46. App. 10/2/42. Assign. The Western Union Telegraph Co.

Apparatus for Recording Electrical Signals. A facsimile recorder which produces a mimeograph type stencil by controlling the impacts on a recording drum produced by a radially oscillating stylus.

U. S. No. 2,403,527. W. D. Hershberger. Iss. 7/9/46. App. 1/30/43. Assign. Radio Corp. of America.

Pulse-Echo Distance Indicator. A radio altimeter in which the received pulse trips trigger circuits arranged so that signal lights are operated when upper and lower limits of altitude or distance are exceeded.

U. S. No. 2,403,535. J. T. Kremer. Iss. 7/9/46. App. 3/18/44. Assign. The Texas Co.

Well Sounding Microphone. An electrodynamic microphone for echo sounding in wells and in which the pressure on two sides of the diaphragm is equalized by connecting the space behind the diaphragm to a rubber bulb the outside of which is under well pressure.

U. S. No. 2,403,704. L. W. Blau. Iss. 7/9/46. App. 3/27/42. Assign. Standard Oil Development Co.

Thermal Prospecting. A thermal prospecting method in which relatively deep holes are drilled, a resistance thermometer inserted, the hole filled with dirt and temperature readings taken at intervals of several days until equilibrium has been established.

U. S. No. 2,403,799. G. E. Holton, C. E. Heglund and J. V. Manson. Iss. 7/9/46. App. 4/28/45. Assign. Hinckley-Myers Division of Kent-Moore Organization, Inc.

Tensiometer. A cable tensiomter in which spring pressure deflects the cable when laid across two anvils and the amount of deflection is measured and converted to tension by referring to an attached table.

U. S. No. 2,403,849. C. E. Cox. Iss. 7/9/46. App. 10/29/43.

Flowmeter Metering Head. A metering float for a variable area tube type of precision flowmeter, the float having two cylindrical faces some distance apart for smoothing the effect of tube surface irregularities.

U. S. No. 2,403,867. D. E. Lipfert. Iss. 7/9/46. App. 11/30/43. Assign. Chandler-Evans Corp.

Flowmeter. A fluid flowmeter having a rotary meter driven by a fluid motor energized from the fluid stream and a differential pressure controlled brake to regulate the speed so as to hold a fixed pressure across the meter element.

U. S. No. 2,403,974. W. D. Goodale, Jr., B. F. Lewis and W. H. Martin. Iss. 7/16/46. App. 12/28/43. Assign. Bell Telephone Laboratories, Inc.

System for Locating the Source of an Explosion Wave. Apparatus for indicating the direction of an underwater explosion wave having two quadrature hydrophones connected through amplifiers to quadrature deflecting plates of a c-r tube.

U. S. No. 2,403,999. T. A. Read, H. I. Fusfeld and S. W. Kitchen. Iss. 7/16/46. App. 2/22/44.

Sonic Method for Testing Metal. A method of testing cylindrical non-magnetic objects for flaws by resonantly exciting the object at high amplitude by means of an electrodynamic drive at one end and observing the damping effect of flaws by means of a strain gauge on the body.

U. S. No. 2,404,360. L. G. Bostwick. Iss. 7/23/46. App. 6/5/42. Assign. Submarine Signal Co.

Tunable Underwater Signal Source. An electrodynamic hydrophone in which the moving system is carried on a spider with circumferential spring arms whose effective length may be adjusted by a rotating adjustment.

U. S. No. 2,404,361. N. Brewer. Iss. 7/23/46. App. 4/27/43. Assign. Fischer & Porter Co.

Rotameter. A rotameter type of flowmeter for convenient insertion in a straight horizontal pipe line and which is constructed of two similar angle fittings clamped together vertically and bored for flow channels.

U. S. No. 2,404,375. W. R. Harry. Iss. 7/23/46. App. 10/15/41. Assign. Bell Telephone Laboratories, Inc.

Electromechanical Device. A pressure gradient type hydrophone having a steel plate with a frame on each side supporting pole pieces which extend into a central opening in the plate and a coil suspended in the annular air gap by radial arms.

U. S. No. 2,404,391. W. P. Mason. Iss. 7/23/46. App. 2/19/42. Assign. Bell Telephone Laboratories, Inc.

Prismatic and High Power Compressional-Wave Radiator and Receiver. A piezoelectric oscillator having a group of crystals successively connected to successive sections of a multi-section filter to produce the proper phase and also having a viscous liquid interposed between the crystals and the transmission medium to reduce cavitation.

U. S. No. 2,404,527. G. Potapenko. Iss. 7/23/46. App. 5/2/39.

Electric Distance Meter. A radio altimeter in which a meter is connected to a circuit coincidentally with the transmission and disconnected at reception of the radio signal so that its deflection is proportional to travel time.

U. S. No. 2,404,764. H. C. Hayes. Iss. 7/23/46. App. 12/16/31.

Sound Receiver. An underwater sound receiver in which sound pressures on the case are applied through a piezoelectric crystal to an inertia mass and the crystal is connected to a preamplifier tube in the same case.

U. S. No. 2,404,784. L. G. Bostwick. Iss. 7/30/46. App. 6/7/40. Assign. Bell Telephone Laboratories, Inc.

Acoustic Device. A hydrophone having a dome shaped diaphragm with a restricted area in contact with the water and having acoustic damping on that part of the diaphragm not exposed to water.

U. S. No. 2,404,785. L. G. Bostwick and J. H. King. Iss. 7/30/46. App. 6/5/42. Assign. Bell Telephone Laboratories, Inc.

Electromechanical Device. A submarine signal generator having a convex diaphragm with a flexible annular ring surrounding it to restrict the diaphragm area exposed to water and having a separate pressure balancing bulb in a separate housing at some distance.

U. S. No. 2,404,786. L. G. Bostwick. Iss. 7/30/46. App. 9/15/42. Assign. Bell Telephone Laboratories, Inc.

Moisture Control in an Electromechanical Device. A desiccating silica gel wrapped in muslin for use inside a hydrophone to take up any water which diffuses through a pressure equalizing bladder connected to the back of the diaphragm.

U. S. No. 2,404,799. W. R. Harry and F. F. Romanow. Iss. 7/30/46. App. 7/3/42. Assign. Bell Telephone Laboratories, Inc.

Submarine Signal Device. A hydrophone having a gradient type transducing element resiliently suspended inside a yielding thin-walled container which is filled with liquid so as to permit energy transfer from the water to the transducing element.

U. S. No. 2,404.975. R. E. Mathes. Iss. 7/30/46. App. 5/29/42. Assign. Radio Corp. of America.

Recording Stylus. A spark recording stylus having a small hole which bears against the drum, the hole carrying two small electrodes separated by an insulator around which the spark jumps close to the recording drum.

U. S. No. 2,405,078. R. A. Ward. Iss. 7/30/46. App. 4/18/44. Assign. R. C. Switzer and J. L. Switzer.

Method and Compositions for Locating Surface Discontinuities. A method of inspecting a body for surface flaws by heating the body, applying a water-emulsifiable luminescent liquid while cooling the body, washing off excess, reheating to exude the luminescent liquid and examining under ultraviolet light.

U. S. No. 2,405,133. W. J. Brown. Iss. 8/6/46. App. 10/7/42. Assign. The Brush Development Co.

Method and Means for Measuring Surface Roughness. A roughness tester having a stylus connected to a multiplate piezoelectric crystal which feeds a push-pull amplifier and two half wave rectifiers whose outputs are integrated, and a meter which may be connected to either or both rectifiers to indicate roughness of peaks or valleys or total roughness.

U. S. No. 2,405,134. W. J. Brown and J. E. Shomer. Iss. 8/6/46. App. 8/3/42. Assign. The Brush Development Co.

Distance Measuring System. A supersonic echo sounding system in which the transmitted wave has a saw tooth variation in frequency and the receiver has a tuned circuit variable in the same way but with an adjustable time delay which is used as the distance indication.

U. S. No. 2,405,179. R. Black, Jr. and F. F. Romanow. Iss. 8/6/46. App. 9/4/41. Assign. Bell Telephone Laboratories, Inc.

Electromechanical Transducer. A hydrophone in which the water actuates a small diaphragm which drives a larger diaphragm carrying the pick-up coil, both diaphragms being damped by air spaces in which external pressure is equalized by small connections through a bellows.

U. S. No. 2,405,182. J. H. Bollman. Iss. 8/6/46. App. 12/10/42. Assign. Bell Telephone Laboratories, Inc.

Ultrasonic Ranging Device. A supersonic ranging system for small boats and using relaxation oscillators to start and stop the signal and time the echo.

U. S. No. 2,405,185. H. Benioff. Iss. 8/6/46. App. 10/8/41. Assign. Submarine Signal Co.

Sound Transmitter and Receiver. An underwater transmitter having a diaphragm with small radiating area and a relatively heavy annular single turn armature in a permanent field, current in the armature being induced by transformer action from an adjacent fixed coil.

U. S. No. 2,405,186. H. Benioff. Iss. 8/6/46. App. 10/8/41. Assign. Submarine Signal Co.

Piezoelectric Vibrator. A supersonic piezoelectric vibrator in which the piston is driven by longitudinally vibrating elements of more than one wave length and with crystals mounted in recesses at their expansion and contraction nodes.

U. S. No. 2,405,187. H. Benioff. Iss. 8/6/46. App. 11/7/41. Assign. Submarine Signal Co.

Piezoelectric Transducer. A supersonic piezoelectric hydrophone having a plate bored to receive longitudinally vibrating crystal units covered by a plug, each plug having a central piston section surrounded by an annular groove to give compliance and an outer ring which is cemented to the plate.

U. S. No. 2,405,199. W. S. Faust and H. J. Lavo. Iss. 8/6/46. App. 4/19/44. Assign. The Aviation Corp.

Fluid Presure Gauge. A fluid pressure gauge in which the pressure load on a diaphragm is transferred to a column carrying an electrical strain gauge.

U. S. No. 2,405,203. M. K. Goldstein. Iss. 8/6/46. App. 9/3/41.

Phase Type Direct Indicating Direction Finder. A radio direction indicator having quadrature antennas, modulating the voltage of one and adding it to the other, and a phase detector which produces a signal at the modulating frequency and of amplitude proportional to the sine of the phase angle between the two antennas' signals.

U. S. No. 2,405,209. W. R. Harry. Iss. 8/6/46. App. 7/3/42. Assign. Bell Telephone Laboratories, Inc.

Submarine Signal Device. A hydrophone having the transducing element suspended in a case filled with a miture of alcohol and glycerine of the same density and compressibility as water.

U. S. No. 2,405,210. A. H. Inglis. Iss. 8/6/46. App. 7/3/42. Assign. Bell Telephone Laboratories, Inc.

Submarine Signal Device. A hydrophone having a gradient type transducing element suspended in an outer container which is filled with a particle-free, gas bubble-free, antifreeze liquid.

U. S. No. 2,405,225. W. P. Mason. Iss. 8/6/46. App. 10/14/42. Assign. Bell Telephone Laboratories, Inc.

Submarine Signal System. A broad band submarine signal projector having a number of 45-degree Y-cut Rochelle salt crystals connected in parallel and a series resistance equal to the reactive impedance of the crystals at the low frequency end of the band.

U. S. No. 2,405,226. W. P. Mason. Iss. 8/6/46. App. 12/28/42. Assign. Bell Telephone Laboratories, Inc.

Low Frequency Projector or Hydrophone. A directional submarine transmitter or hydrophone having an array of bimorph crystals mounted on the hull of the ship and with electrical phase shifting networks between the crystals to impart directivity.

U. S. No. 2,405,227. W. P. Mason. Iss. 8/6/46. App. 3/20/43. Assign. Bell Telephone Laboratories, Inc.

Geometrical Instrument. A plotting device for graphically locating the position of a submarine sound source from the signals received from the three legs of a triangular array of hydrophones.

U. S. No. 2,405,281. E. W. Bemis. Iss. 8/6/46. App. 9/22/42. Assign. American Telephone and Telegraph Co.

Object Locator. A device for determining the direction of a wave source by rotating a microphone or antenna in a circular orbit and comparing the note received with that received by a stationary microphone or antenna and orienting the plane of rotation until no Doppler effect is observed.

U. S. No. 2,405,382. E. Volet. Iss. 8/6/46. App. 2/5/42, 2/24/43 and 6/28/43.

Accelerometer. An accelerometer for rotating machines having a rotating inertia mass connected through an elastic torque rod and in which angular displacements of the inertia mass are detected by an air jet rotating with the machine.

U. S. No. 2,405,572. H. Friedman. Iss. 8/13/46. App. 8/3/43.

Radiographic Exposure Meter. A form of Geiger-Mueller counter for measuring the intensity of hard X-rays having an insulating case, a hollow cylindrical X-ray permeable cathode and a central anode wire and a small radiation source in the same case to be used for calibration.

U. S. No. 2,405,595. J. F. G. Miller and R. MacHenry. Iss. 8/13/46. App. 2/3/42.

Means for Installing Magnetic Detecting Devices and Supports Therefor. Apparatus for jetting pipe into the floor of a body of water for installing underwater magnetometers at known depth and position on a range for obtaining the magnetic signature of a ship.

U. S. No. 2,405,604. T. J. Pope. Iss. 8/13/46. App. 3/13/43. Assign. Bell Telephone Laboratories, Inc.

Compressional Wave Translating Device. A piezoelectric supersonic hydrophone having a directional characteristic and having a central element and four surrounding elements cemented to the diaphragm, the surrounding elements being one-half wave length apart with diagonal elements connected in opposition.

U. S. No. 2,405,605. W. D. Goodale, Jr. and F. F. Romanow. Iss. 8/13/46. App. 9/2/43. Assign. Bell Telephone Laboratories, Inc.

Signal Translating Device. A piezoelectric supersonic underwater transmitter radiating in a plane normal to its axis and having a linear crystal array on each side of a square central post.

U. S. No. 2,405,704. M. P. Matuszak. Iss. 8/13/46. App. 10/21/43. Assign. Phillips Petroleum Co.

Flowmeter. A resistance pressure drop flowmeter in which the gas is passed radially through a porous tube whose effective length may be varied by raising mercury into the surrounding annular space.

U. S. No. 2,405,912. G. A. Tinnerman. Iss. 8/13/46. App. 8/26/42. Assign. Tinnerman Products, Inc.

Detonator Clamp. A clamp for connecting an igniter to a frangible bottle of incendiary fluid and holding the firing pin of the igniter so that when the bottle is broken the igniter is discharged.

U. S. No. 2,406,014. W. R. Harry. Iss. 8/20/46. App. 12/28/43. Assign. Bell Telephone Laboratories, Inc.

System for Locating the Source of an Explosion Wave. An underwater explosion direction indicator having quadrature hydrophones with amplifiers feeding peak rectifiers whose output is applied to quadrature deflecting plates of a c-r tube.

U. S. No. 2,406,119. A. L. W. Williams and A. P. Dank. Iss. 8/20/46. App. 3/11/42. Assign. The Brush Development Co.

Microphone. A crystal microphone responding to spherical sound waves from a nearby source and having two pressure gradient sound cells connected in opposition and spaced apart so that the effect of plane waves cancel out but spherical waves originating nearby produce a signal.

U. S. No. 2,406,181. F. J. Wiegand. Iss. 8/20/46. App. 1/14/43. Assign. Wright Aeronautical Corp.

Flowmeter. A venturi type flowmeter for use in gas lines in which the deflection of a large diaphragm subjected to the venturi differential pressure is balanced by attaching a smaller diaphragm whose larger differential pressure is measured.

U. S. No. 2,406,358. S. Doba, Jr. Iss. 8/27/46. App. 3/21/44. Assign. Bell Telephone Laboratories, Inc.

Ground Speed Meter. An airplane ground speed meter in which a radar reflection produces a moving spot on a c-r tube screen and a local voltage producing a line on the tube is adjusted to vary linearly with time at the same rate.

U. S. No. 2,406,391. W. P. Mason. Iss. 8/27/46. App. 1/6/42. Assign. Bell Telephone Laboratories, Inc.

Compressional Wave Directional, Prismatic, and Focusing System. A directional wave transmitter or receiver having an array of acoustical elements arranged with proper acoustic time delays between them to obtain directivity.

U. S. No. 2,406,529. A. D. Blumlein. Iss. 8/27/46. App. 1/10/40 and 6/13/42. Assign. Electric & Musical Industries, Ltd.

Electrical Apparatus for Indicating or Measuring Distances. An aircraft altimeter having two condenser plates on the wings connected in a bridge circuit with tightly coupled inductances.

U. S. No. 2,406,597. H. T. Faus. Iss. 8/27/46. App. 9/7/44. Assign. General Electric Co.

Electric Pickup. An electromagnetic phonograph pickup in which the stylus and coil are rubber mounted so as to rotate the coil about an axis at right angles to the field of a magnet.

U. S. No. 2,406,792. H. Benioff. Iss. 9/3/46. App. 7/8/40. Assign. Submarine Signal Co.

Piezoelectric Oscillator. A tuned piezoelectric transducer having a plate with longitudinally vibrating driving units fastened to it, the driving units being columns and having end abutments between which the crystals are cemented.

U. S. No. 2,406,836. W. H. T. Holden. Iss. 9/3/46. App. 3/24/44. Assign. Bell Telephone Laboratories, Inc.

Electric Air Position Indicator. An airplane position indicator which indicates latitude, longitude and air miles flown and having an air speed indicator whose components are derived from a compass repeater and separately operate the latitude and longitude indicators.

U. S. No. 2,406,982. V. K. Zworykin and J. Hillier. Iss. 9/3/46. App. 6/20/42. Assign. Radio Corp. of America.

Electronic Vibration Detecting Apparatus. A vibrometer in which the electron beam in a spring suspended electron microscope is focused on a knife edge which is mechanically connected to the vibrating body.

U. S. No. 2,407,140. C. F. Coake. Iss. 9/3/46. App. 8/2/44. Assign. Senn Corp.

Electric Microgauge Sysgem. An electric microgauge in which the moving element varies oppositely the air gap of two inductances in an impedance bridge so as to change the phase balance and the phase shift is indicated.

U. S. No. 2,407,141. C. F. Coake. Iss. 9/3/46. App. 2/15/45. Assign. Senn Corp.

Electric Microgauge System. An electric microgauge in which the moving element changes the impedance balance between two coils tuned with condensers and connected in an impedance bridge and the bridge unbalance is indicated.

U. S. No. 2,407,175. P. Orlich, G. Negel and H. Hartz. Iss. 9/3/46. App. 5/2/39 and 11/14/40. Vested in Alien Property Custodian.

Echo Sounding Device. An air driven siren or whistle sound source having a tuned chamber in which the distance from the vibration producing ports to the remote wall is an uneven multiple of quarter wave lengths.

U. S. No. 2,407,243. L. Batchelder. Iss. 9/10/46. App. 7/27/33. Assign. Submarine Signal Co.

Magnetostriction Oscillator. A supersonic vibrator having half wave length magnetostrictive tubes mounted on the back of a vibrating plate.

U. S. No. 2,407,244. L. Batchelder. Iss. 9/10/46. App. 8/2/39. Assign. Submarine Signal Co.

Apparatus for Submarine Signaling. A directional hydrophone in which a different beam pattern in two planes is obtained by having an array of driving elements mounted on the radiating diaphragm and arranged so as to impart a diaphragm amplitude which is symmetrical about a diameter.

U. S. No. 2,407,256. E. B. Dallin. Iss. 9/10/46. App. 6/15/33. Assign. Submarine Signal Co.

Submarine Signaling Apparatus. A magnetostriction hydrophone having tuned magnetostrictive tubes welded to a diaphragm and bolted to a heavy backing plate and with air pressure supplied between the plate and the diaphragm to relieve the magnetostrictive tubes of pressure loading due to water pressure.

U. S. No. 2,407,271. H. M. Hart. Iss. 9/10/46. App. 7/22/39. Assign. Submarine Signal Co.

Apparatus for Submarine Signaling. A directional hydrophone in which a beam pattern without large side lobes is obtained by separately exciting the zones of a circular radiating surface at amplitudes which vary from a maximum at the center to minimum at the edge according to a known formula.

U. S. No. 2,407,273. R. W. Hart. Iss. 9/10/46. App. 3/5/35. Assign. Submarine Signal Co.

Method and Means for Distance and Direction Finding. A radio distance finder in which a c-r tube beam with circular sweep controls the transmission of a pulse by striking a keying electrode and the distance to the reflector is indicated by the angular movement of the beam during the transmission time.

U. S. No. 2,407,282. J. K. Johnson. Iss. 9/10/46. App. 12/18/41. Assign. Hazeltine Research, Inc.

System for Indicating Mechanical Motion. An electrical system for indicating small amounts of relative angular motion in a radio direction finder by having the motion vary the coupling between two coils one of which is excited with high frequency current and detecting the modulation effect in the second coil.

U. S. No. 2,407,294. W. Shockley and G. W. Willard. Iss. 9/10/46. App. 4/17/42. Assign. Bell Telephone Laboratories, Inc.

Wave Propagation Device. Apparatus for comparing the travel time of a reflected radio signal with the transmission time of a compressional pulse in a small tank having a driving crystal and receiving crystal with adjustable distance between them and a liquid mixture having zero temperature coefficient of velocity.

U. S. No. 2,407,299. E. W. Smith. Iss. 9/10/46. App. 1/10/34.

Communication in Pipe Lines. A transmitter for impressing high frequency compressional waves on a pipe line having a collar on the pipe and a series of magnetostrictive elements fastened to the collar with their longitudinal axes parallel to the pipe.

U. S. No. 2,407,315. W. P. Mason. Iss. 9/10/46. App. 10/6/43. Assign. Bell Telephone Laboratories, Inc.

Liquid Medium for Ultrasonic Compressional Wave Transmission. A mixture of dimethyl phthalate and xylene hexafluoride having high cohesion and high vapor pressure for transmitting large amounts of ultrasonic vibration power.

U. S. No. 2,407,328. E. E. Turner, Jr. Iss. 9/10/46. App. 6/23/33. Assign. Submarine Signal Co.

Sending and Receiving Apparatus. A magnetostriction vibrator having a series of magnetostrictive tubes with one free end and mounted either on a radiating plate or on the inner end of a horn.

U. S. No. 2,407,329. E. E. Turner, Jr. Iss. 9/10/46. App. 7/22/39. Assign. Submarine Signal Co.

Apparatus for Submarine Signaling. A directional magnetostriction hydrophone in which a beam pattern without large side lobes is obtained by using a circular radiator of diameter many times the wave length and exciting it in zones of graduated amplitude either by using magnetostrictive elements of different ampere-turns in each zone or by making the radiator zones of graduated thickness.

U. S. No. 2,407,330. E. E. Turner, Jr. Iss. 9/10/46. App. 2/6/41. Assign. Submarine Signal Co.

Direction Determining System. An underwater sound direction recording system in which a directional hydrophone is rotated in synchronism with a rotating recording drum and the drum is slowly moved along its axis so that sustained sounds result in a line on the record.

U. S. No. 2,407,363. W. H. Bussey. Iss. 9/10/46. App. 2/17/45. Assign. O. W. Storey & Associates.

Electrical Apparatus. A transducer using the capillary electrometer principle to detect motion with the mercury of the electrometer acting as the steady mass.

U. S. No. 2,407,643. L. Batchelder. Iss. 9/17/46. App. 8/2/39 and 8/3/40. Assign. Submarine Signal Co.

Apparatus for Submarine Signaling. A directional hydrophone in which a different beam pattern in two planes is obtained by shaping the radiating surface differently with respect to two center lines.

U. S. No. 2,407,644. H. Benioff. Iss. 9/17/46. App. 7/29/40. Assign. Submarine Signal Co.

Ranging System. A distance measuring system in which the transmitted signal is

cyclically modulated both in frequency and amplitude while the receiver is synchronously varied in tuning and sensitivity in the reverse direction, the distance being determined from the received frequency.

U. S. No. 2,407,649. H. T. Budenbom. Iss. 9/17/46. App. 7/23/41. Assign. Bell Telephone Laboratories, Inc.

Direction Finding System. A radio direction finding system in which two vertical antennas are mounted on a turntable and their direction adjusted so that there is no phase difference between their signals as indicated on a c-r tube.

U. S. No. 2,407,661. B. M. Harrison. Iss. 9/17/46. App. 4/26/40. Assign. Submarine Signal Co.

Submarine Signaling Device. A submarine signaling system having a number of directional hydrophones in a blister on the ship's hull, the hydrophones being either connected in parallel for distance determinations or connected to separate tuned phase shifting circuits for direction determination.

U. S. No. 2,407,662. H. M. Hart. Iss. 9/17/46. App. 7/22/39 and 7/8/40. Assign. Submarine Signal Co.

Method and Apparatus for Submarine Signaling. A directional hydrophone in which a beam pattern without large side lobes is obtained by having a circular radiating surface whose zones are separately excited at amplitudes $A_r/A_0 = 1 - 12r^2/7a^2 + 6r^4/7a^4$, where r is the distance from the center and a is the maximum radius of the radiator.

U. S. No. 2,407,663. R. W. Hart. Iss. 9/17/46. App. 1/24/39. Assign. Submarine Signal Co.

Method and Means for Distance and Direction Finding. An aircraft radio altimeter having two *c-r* tubes with synchronized circular sweep, the transmission of the signal being controlled by the beam passing a keying electrode in one tube and the transmission time being indicated by the angular position of the beam in receiving tube when the reflected signal is received, the transmitting and receiving systems being shielded from each other.

U. S. No. 2,407,697. R. L. Williams. Iss. 9/17/46. Appl 9/14/35. Assign. Submarine Signal Co.

Apparatus for Submarine Signaling. A ship's hydrophone mounted in gimbals inside a water filled protective case and oriented vertically by a pendulous weight or kept oriented in any desired direction by the use of servo-motors controlled from a gyro in the ship.

U. S. No. 2,408,028. L. Batchelder. Iss. 9/24/46. App. 1/19/34. Assign. Submarine Signal Co.

Means for Sending and Receiving Compressional Waves. A directional piezoelectric hydrophone having a rectangular array of rectangular pressure type crystals, each row being excited at proper phase, and with the crystal elements tuned considerably above operating frequency of the hydrophone.

U. S. No. 2,408,035. H. Benioff. Iss. 9/24/46. App. 10/22/41 and 10/9/42. Assign. Submarine Signal Co.

Observation System. A multichannel spark recorder for a compressional wave harbor area observation system in which the sparking beads are moved over the recording drum at a rate proportional to the velocity of sound in water and carried on wires representing the direction of the associated hydrophone.

U. S. No. 2,408,113. E. E. Turner, Jr. Iss. 9/24/46. App. 7/22/39 and 8/26/41. Assign. Submarine Signal Co.

Apparatus for Submarine Signaling. A directional hydrophone in which a beam pattern without large side lobes is obtained by using a circular radiating member whose zones are of varying thicknesses and are separately excited by transducing elements, each transducer and its associated part of the radiator being a half wave length system.

U. S. No. 2,408,230. W. E. Shoupp. Iss. 9/24/46. App. 12/9/41. Assign. Westinghouse Electric Corp.

Measuring Apparatus. A neutron detector made by coating the inner surface of the cylinder in a Geiger counter with fissionable material such as uranium or thorium.

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REVIEWS

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Shoran precision radar, by Stuart William Seeley. Electrical Engineering, vol. 65, no. 4 (April 1946), Transactions Section, pp. 232–240.

Use of shoran in geodetic control, by Carl I. Aslakson and Donald A. Rice. Transactions, American Geophysical Union, vol. 27, pp. 459–463 (1946).

These two papers discuss Shoran, which is an electronic method of measuring the distance between a mobile station and a fixed station with a high degree of precision. In practice, the location of the mobile station is determined by measuring the distances to two fixed stations at accurately known and accessible points.

A short pulse, with duration less than a microsecond, is transmitted, at a radio frequency between 210 and 320 megacycles, from the mobile station to a fixed station. The fixed station then automatically transmits a pulse, on a different radio frequency, in the same band. This pulse is transmitted with a precisely fixed and known time delay after the receipt of the pulse from the mobile station. This return pulse is received at the mobile station and the time elapsing between the initial transmission and the receipt of the return pulse gives the distance between the mobile station and the fixed station with an accuracy determined by the accuracy of the measurement of this time difference, the accuracy of the delay at the fixed station, and the accuracy with which the velocity along the propagation path of the pulse is known. In the same manner, by transmitting a pulse on a different radio frequency, the distance from the mobile station to a second fixed station is determined.

The transmitter power and receiver sensitivity are such that a range of 250 miles from mobile station to fixed station can be covered. However, because of the frequencies employed, the range is limited essentially to line of sight and so is determined largely by the elevation of the antennas. The maximum range is attainable only when the mobile station is in an airplane.

The first paper, written by a man who has been closely associated with the development of Shoran, describes its interesting and instructive history. The construction and operating method of the present version of Shoran is discussed in rather general terms and photographs of both the mobile and fixed equipment are included.

The second paper describes an application of Shoran to geodetic control developed by the 311th Reconnaissance Wing, U. S. Army Air Forces, in cooperation with the Division of Geodesy, U. S. Coast and Geodetic Survey. In this work, the distances between pairs of previously established first-order triangulation points 148 to 307 miles apart were measured by flying back and forth across the lines joining the triangulation points and determining the minimum values of the sum of the distances from the airplane to the ground stations set up at pairs of the triangulation points. The paper contains a discussion of various sources of error and details of the method of observation and computation. The observed errors ranged from 1 ft. in a distance of 308 miles,

to 45 ft. in a distance of 199 miles, the average error being 21 ft. in approximately 200 miles.

This new tool may prove useful in some phases of geophysical prospecting. It is being used at present for determining the position of seismograph locations in the Gulf of Mexico. In foreign areas where no accurate maps are available, it may be useful in establishing a net of accurately determined control points.

W. M. RUST, JR.

Shoran precision radar, by Stuart William Seeley. Electrical Engineering, vol. 65, no. 4 (April, 1946). Transactions Section, pp. 232–240.

This published article is substantially the material which was presented by Mr. Seeley under the same title at the Sixteenth Annual Meeting of the Society of Exploration Geophysicists at Chicago, Illinois, in April, 1946. For that reason, this more extended review is included as well as the shorter one in the preceding review.—*Editor*

This article covers Shoran radar from angles of history of the equipment, theory of operation, and some of the applications.

The original ideas of Shoran evolved out of the "ghost images" that complicated

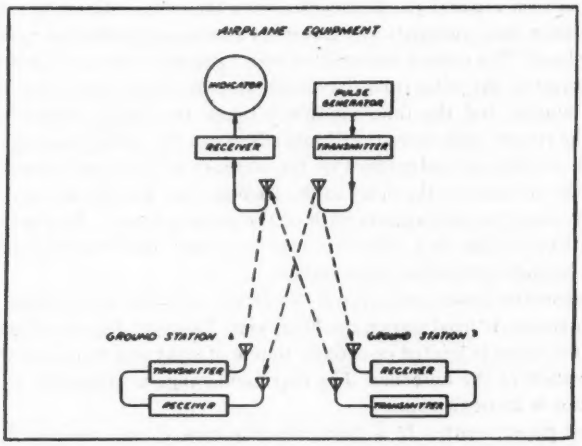


FIG. 1. Block diagram of basic Shoran system.

the early development of television. It was learned that the displacement of a "ghost image" bore a direct relation to the increased path length of the signal which caused this "ghost." This knowledge led to the belief that relatively long distances could be accurately measured through the use of a time-delay yardstick.

The fundamental principle of Shoran is that of a mobile or air station pulse transmitting to two ground stations at two frequencies. Each of these ground stations retransmits the signal back to the air station, where the time elapsed for each signal is converted into distance from each of the ground stations (Fig. 1). Thus, when the posi-

tions of the two ground stations are accurately known, the exact position of the air station is known.

The airborne transmitter transmits pulsed signals on two frequencies between 220 and 260 megacycles and separated by 5 to 10 megacycles. The pulse repetition rate is 931.09 cycles per second. The period of one cycle of oscillation at this frequency is equivalent to the time required for a radiated signal to travel a round trip distance of

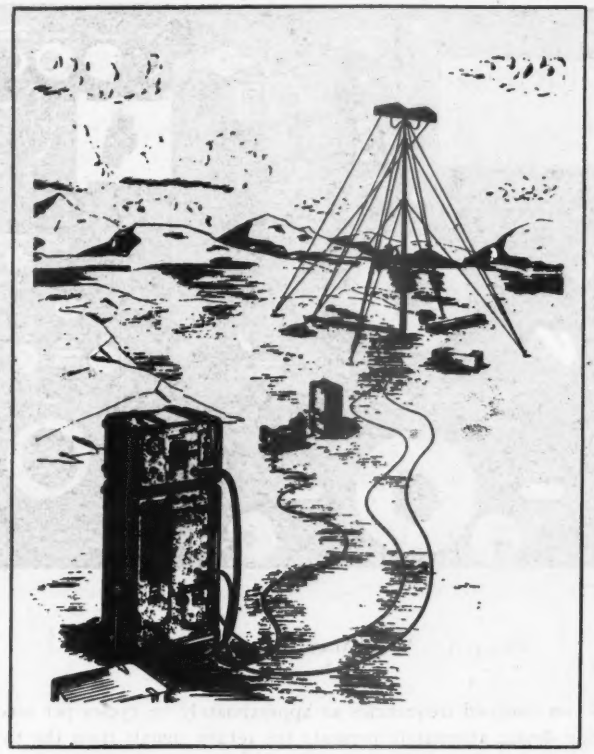


FIG. 2. A Shoran ground station.

one hundred miles. The transmitter is switched between these frequencies at a rate of approximately 10 cycles per second.

The two accurately located ground stations are each tuned to receive on one of the above-mentioned frequencies.

The ground stations each receive, reshape, amplify, and retransmit the pulse at a frequency between 290 and 330 megacycles. These ground stations contain a variable delay and a fixed delay network which are so arranged that the over-all delay of a signal through a ground station may be compared and made equal to the fixed delay network (Fig. 2). Thus, the airborne equipment may at all times be compensated for a predetermined signal delay through the ground station.

The airborne equipment also has a means whereby it may be "zero set"; that is, the signal delay through it may be compensated for.

The signals after having been retransmitted from the ground stations are received at the airborne equipment, and the total elapsed time for each signal is accurately indicated within 1/100 mile and can be estimated to 1/1000 mile.

As has been previously mentioned, the airborne equipment alternately switches

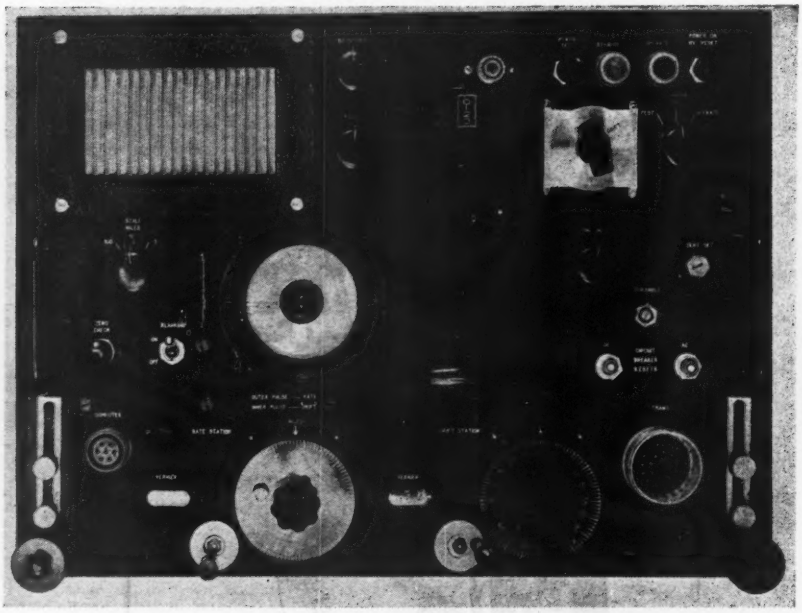


FIG. 3. AN/APN3 Manual airplane equipment.

between the two assigned frequencies at approximately 10 cycles per second. This same switching device alternately presents the return signals from the two ground stations in such a manner that they can be identified as belonging to either of the two ground stations.

The basic indicating device of the system is a cathode ray tube employing a circular sweep. Distance readings are obtained by varying the phase of the transmitted pulse sufficiently so that the return signal will coincide with the marker pulse on the cathode ray tube. This phase shift is done by means of quadrature networks (goniometers). These phase shifters are accurately calibrated to 1/100 mile by use of counters of the Veeder-type (as in odometers). In the plane, there are separate mileage dials and counters for each ground station (Fig. 3).

Another feature which adds greatly to the accuracy is the stability of the repetition rate of the transmitted pulses, which is controlled by a quartz crystal oscillator to an accuracy of 1 part in 1 million.

This equipment has a proven accuracy of not more than ± 50 feet out to the limit of its range (approximately 250 miles).

During the war, Shoran was used for navigation and precision bombing. It is being used today by Army geodetic and mapping groups "for establishing control points with first order survey accuracy at very great distances."

This equipment may be used to fly a specified arc or to fly to a predetermined position. The latter is done by flying about one ground station in an arc equal to the target distance from that station. Thus, the desired location will be reached when the proper distance from the second ground station is reached (Fig. 4). For this type of operation.

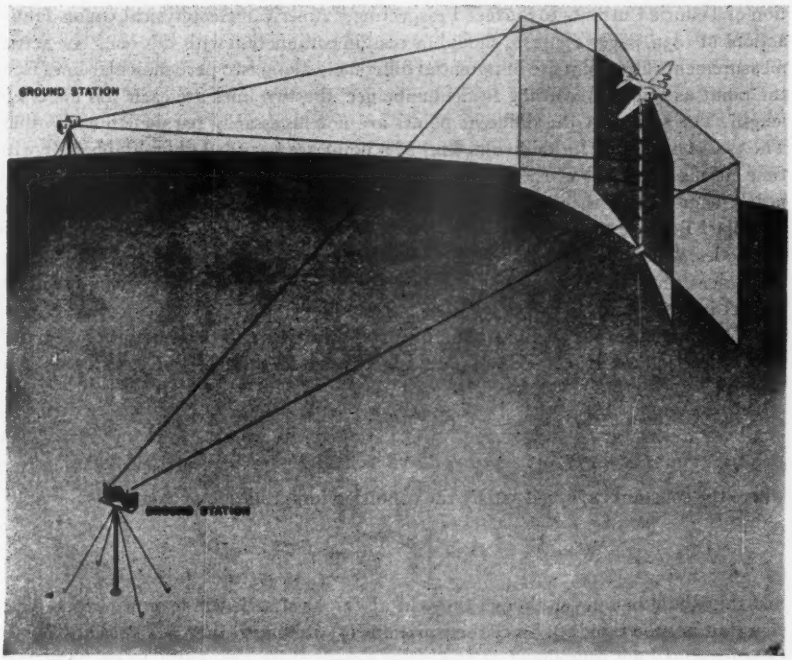


FIG. 4. Two distances "fix" the airplane: The Shoran set indicates plane's distance from two ground stations, thus "fixing" it at intersection of the corresponding circular arcs swung around the two stations.

a pilot direction indicator is in front of the pilot. With this equipment, it is possible "to keep the plane on its arc path with deviations less than the span of the plane wings."

The paper by Mr. Seeley does not mention the possible applications of Shoran surveying with respect to geophysical exploration; however, it is felt that this equipment may be profitably employed for this purpose.

Figures 3 and 4 are from Seeley's paper and are reproduced by permission of A.I.E.E. from photographs supplied by Mr. Seeley, while Figures 1 and 2 are from "Handbook of Maintenance Instructions for Radio Set AN/CPN-2, approved 7 December 1944."

WILFRED A. FRIEDMAN

Une méthode nouvelle de géophysique appliquée; la prospection par courants telluriques (A new method of applied geophysics; prospecting by telluric currents), by Léon Migaux, Annales de Géophysique, 2, 131–146 (1946).

The earth currents which are used in this method of prospecting are the world-wide natural currents which are believed to be a reflection of electric phenomena in the upper reaches of the atmosphere which are directly related to solar radiations. Over squares 100 km. on a side, these currents would be sensibly parallel for a homogeneous crust, but "structures" or other heterogeneities would produce anomalies in these currents. The principle of the method is to detect and interpret these anomalies.

This method was initiated by Marcel Schlumberger, whose article, "The Application of Telluric Currents to Surface Prospecting," American Geophysical Union Transactions of 1939, pages 271–277, should be read in conjunction with this one. The actual measurements at a point are of potential differences along two perpendicular lines from the point as origin. According to Schlumberger, the two lines are each 500 meters in length. The setups at the different points are not necessarily parallel to each other. The two components (in millivolts/km) at a point are recorded photographically with time marks indicated every thirty seconds. The field is highly agitated, sometimes nearly sinusoidal with periods from ten seconds to several minutes, sometimes very irregular. Because of the great difficulty of determining the contact potential of the electrodes, which may not stay constant for long periods, the quantities used are the differences (in each component) between the values measured at two instants of time a short interval apart.

For a homogeneous medium of infinite extent the two surface components, X and Y, of the electric field at a station M would be related to those, x and y, at a base A as follows:

$$\left.\begin{aligned} X &= ax + by \\ Y &= cx + dy, \end{aligned}\right\} \tag{1}$$

where the constants a, b, c, d satisfy the condition for a rotation of axes

$$D = \begin{vmatrix} a & b \\ c & b \end{vmatrix} = 1,$$

and this would be so even though the field at the base varied in magnitude and direction (but not too rapidly). Since the equations (1) are linear, they will hold also for the differences of each component at two given times, which quantities, as we have mentioned, are those actually used. If the medium were not homogeneous but had different restivities over widely extended regions, one containing M and one containing A, it is conceivable that a set of four constants might exist so that the equations (1) would hold at least approximately with the determinant, D, now greater or less than one, indicating in a fashion the differing resistivity at M as compared to A. But that such sets of constants could be found even when A and M are on the surface of a definitely non-homogeneous earth 20 to 25 km. apart and for simultaneously measured differences over 10 to 30 seconds is something that could hardly be expected. Nevertheless, such has been found to be the case for many thousands of such pairs of experimental setups made in France.

It can be shown that if the variations in x and y are selected so that they lie on a circle of radius unity, then the corresponding variations in X and Y lie on an ellipse

which is completely determined by the four constants, a, b, c, d. Moreover, the ratio of the area of this ellipse to that of the circle is equal to D. Since D is the quantity ordinarily employed in interpretation (although other quantities such as field vectors and equipotentials may be used), the graphical method is a convenient way of deriving it. The ellipse construction also shows graphically how accurately the equations (1) are satisfied by the four constants. In one case described, in which A and M were 205 km. apart and there was considerable dispersion of the points, it was still possible to draw a mean ellipse.

The author emphasizes the value of this method for petroleum exploration. Sediments, which are in general good conductors, lie on crystalline basements of perhaps a hundred times greater resistivity, As a consequence, the electric field at the surface depends almost entirely on the sediments, a trait which sharply distinguishes the electric from the other natural fields, those of gravity and magnetism. In fact, for a two-dimensional case in which the basement is gently wrinkled, D is proportional to the current density, which in turn to a first approximation equals the total current divided by the thickness of sediments. Thus D in this case is inversely proportional to the sedimentary thickness and a contour map of D, numbered suitably, is a basement depth map.

A more complicated theoretical example of buried limestone outcrops above an anticlinal basement is discussed. Such a structure appears to be present in a survey (in the Midi of France) which is presented as an example and compared with seismic reflection profiles. The locations of synclines and anticlines by both methods are consistent.

The author regards this new method as intermediate between gravimeter and the reflection seismograph for sedimentary exploration, with special advantages on vertical structures. It has been applied commercially in France since 1941 and with it the Compagnie Générale de Géophysique is said to have discovered or detailed numerous structures in Aquitaine and Languedoc.

THOMAS A. ELKINS

"Recent Results in Submarine Geophysics," by Maurice Ewing, G. P. Woollard, A. C. Vines, and J. L. Worzel. Bull. G.S.A. v. 57, pp. 909–934, October 1946.

In 1937 and 1938, Dr. Ewing and his associates published the first results of their refraction work in the submerged part of the Coastal Plain. This work had the important result of indicating a thickness of at least 12,000 feet of sediments off the coast of Virginia, a result which gave considerable impetus to the search for oil which is now being carried on in the neighboring state of North Carolina. But of even greater importance than the data obtained was the development of a technique of shooting in open water in depths as great as 1,600 fathoms.

It is gratifying to learn from the present paper that the technique of deep-water shooting has been so improved that, in the author's words, "The greatest depths of the ocean could be worked nearly as well as lesser depths." The importance of this development for geological science is readily appreciated when we realize that at present we know almost nothing of the geology of the seven-tenths of the earth's surface which is covered by water.

To the petroleum geologist and geophysicist the techniques developed for deep-

water shooting will probably be of less immediate interest than those used in the shallow waters of the Continental shelves, where it seems likely that drilling may be possible in the not too distant future. The shallow water investigations reported in this paper were part of a war project carried out by the Woods Hole Oceanographic Institute for the Navy Department, at a number of widely separated localities; Chesapeake Bay, Jacksonville, Virgin Islands, Barbados, and the mouth of the Orinoco River. This work has yielded significant and fundamental data on the transmission of sound in shallow water, which should be of interest to all seismologists. It is demonstrated by means of high-speed photography that when the shot is placed below a certain critical depth the result is an oscillating gas bubble which gives rise to a series of energy bursts separated by a constant interval of time. Evidence is also given for dispersion, a phenomenon which is observed when the wave length of the sound approaches the water depth. It is intimated that this subject will be treated more fully in a future paper. Both of these phenomena should be of vital interest to anyone engaged in or contemplating seismic work in shallow water.

As a result of this shallow-water shooting, depths to basement were computed from the time-distance graphs for the several localities. Probably the most remarkable of these is the profile obtained off the mouth of the Orinoco River, where a change from a velocity of 11,250 feet per second to one of 21,750 feet per second is clearly shown, and interpreted as the surface of the basement at a depth of 22,700 feet. Although this is very much deeper than the depths usually reached by seismic work on land, the break in the time-distance graph is so sharp and the points are so distributed that no other interpretation seems possible.

Another topic in the paper, while it may have no direct application to prospecting, will appeal to the geophysicist as an example of an extremely ingenious application of the laws of refraction on an oceanic scale. Briefly, the decrease in temperature and the increase in pressure with depth result in a minimum velocity at a depth of about 750 fathoms; it was discovered that with shot and receiver at this depth, the energy is largely channeled, as in a speaking tube, so effectively that a small bomb has been heard at a distance of 3,100 miles. Some practical applications, such as position fixing and shoal discovery, are pointed out.

Two other topics reported, submarine photography and bottom sampling, demonstrate how the ingenuity of the physicist is aiding in the study of submarine geology.

The paper is well illustrated by charts, drawings, and photographs of seismic records. It is rather too brief for the number of topics covered, but it is evidently meant to be only a progress report. It has whetted our appetite, however, and we look forward to some more detailed papers at some time in the future. We believe that the work of Dr. Ewing and his associates is not only providing much needed data on submarine geology, but is doing a great deal to advance the art and science of refraction seismology.

D. C. SKEELS

Some integral equations of potential theory, by H. Bateman, Journal of Applied Physics, 17, 91–102 (1946).

In this paper, Professor Bateman discusses several integral equations of interest to geophysicists. Frequently the value of a geophysical quantity, measurable at the surface of the earth, may be computed by integrating the product of a physical property

(for example, the density or resistivity) of the various portions of the subsurface by some weighting function over a certain subsurface volume, area, or line. If instead of knowing the variation of a physical property and computing the values of the geophysical quantity, one attacks the inverse problem of determining the variation of the physical property of the subsurface from measurements of the geophysical quantities at the surface, these integrals become integral equations. Thus the distribution of mass at a given depth which will produce a given gravity picture is given by the solution of a particular integral equation.

This paper will prove both interesting and useful to those engaged in theoretical work and will serve as an introduction to the many papers included in its bibliography. However, the interpreter will be unable to apply the results of this paper directly to his work. In an effort to cover a wide territory, the treatment has been deliberately made sketchy. For example, such an interesting and important question as whether it is possible for the observed potential to be produced by any distribution of mass at a given depth is passed over by saying the potential is "presumably of the right type for representation by such an expression." Not only are the theoretical limitations of the methods left undiscussed, but the solutions arrived at are invariably in forms which make their application to empirical data a practical impossibility.

W. M. Rust, Jr.

Per un sistema di riferimento „internazionale„ delle misure di gravita—Nota preliminare (Preliminary note on an international reference system for gravity measurements) by Carlo Morelli, Geofisica Pura e Applicata, 8, 81–93 (1946).

This paper concerns the establishment of a new, world-wide, absolute reference value of the acceleration of gravity. The paper reviews the various gravity reference points which have been adopted from time to time as bases of absolute gravity values for relative gravity measurements throughout the world. It is pointed out that heretofore the adopted reference point usually has been a single absolute gravity station which was considered at the time to be the most accurate in the world, and that the adopted reference value together with all dependent relative data has changed from time to time as apparently better absolute gravity determinations became available. The principal point of the paper is the recommendation that an "International System" should be adopted based on an adjustment of the world-wide gravity net including all important absolute gravity stations.

The official basis for all gravity values throughout the world is now Kühnen and Furtwängler's absolute gravity determination in 1898–1904 at Potsdam, Germany—the so-called "Potsdam System." This was considered for many years to be the most precise absolute gravity determination but, in recent years, evidence has accumulated that the Potsdam System is rather badly in error. The author has assembled much data bearing on this question which are summarized in the accompanying table. The gravity values at the various absolute gravity stations in the Potsdam System (the eighth column in the table) were computed by the author from an adjustment of the relative gravity connections between them. It is evident from the last column in the table that the gravity values in the Potsdam System are higher than most of the other measured absolute gravity values, and especially so for the modern ones.

TABLE 1. PRINCIPAL ABSOLUTE GRAVITY MEASUREMENTS

Station	Latitude	Longitude	Elev. Meters	Year	Observer	Observed g	g in Potsdam System	Δ
Rome	41°54.′0 N	12°29.5′ E	59	1882–87	Pisati & Pucci	980.343	980.363	−0.020
Madrid	40°24.′5 N	3°41.′3 W	657	1882	Barraquer	979.981	979.981	0
Paris	48°50.′2 N	2°20.′3 E	61	1883	Defforges	980.943	980.946	−0.003
Vienna	48°13.′9 N	16°20.′4 E	237	1884	v. Oppolzer	980.859	980.853	+0.006
Padua	45°24.′0 N	11°52.′5 E	19	1885–86	Lorenzoni	980.648	980.656	−0.008
Monaco	48°08.′7 N	11°36.′6 E	529	1887	v. Orff	980.736	980.733	+0.003
Potsdam	52°22.′9 N	13°04.′1 E	87	1898–1904	Kühnen & Furtwängler	981.274	981.274	0
Washington	38°56.′5 N	77°03.′9 W	95	1929–30	Heyl	980.080	980.100	−0.020
Leningrad	59°56.′5 N(?)	30°18.′1 E(?)	6(?)	1906–11	Ivanoff	980.929	980.933	−0.004
Teddington	51°25.′2 N	0°20.′3 W	9	1933–1938	Baskov Clark	981.1815	981.196	−0.015

The author then computes a weighted average value at Potsdam (unfortunately without using the recent absolute gravity result at Teddington which was not available to him at the time), which is found to be 12 mg. lower than the presently adopted value of 981.274 gals.

On this tentative basis, the author points out that the present International Gravity Formula (adopted in 1930)

$$g=978.049\ (1+0.0052884\ \sin^2\phi-0.0000059\ \sin^2 2\phi)$$

should be changed to

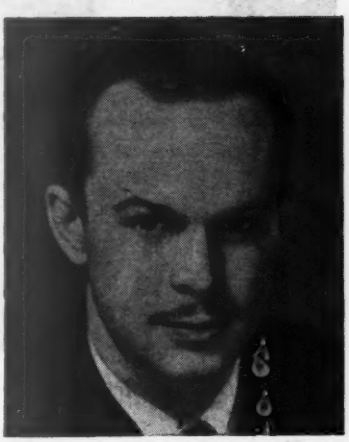
$$g=97\ .037\ (1+0.0052885\ \sin^2\phi-0.0000059\ \sin^2 2\phi).$$

A more complete assembly of data and further study of the problem by interested geodesists are urged. The original paper should be consulted for details and bibliographic references.

When we consider that the absolute gravity determinations now available are much less precise than the relative gravity connections between them, the author's proposal of a World Gravity Reference System based on all available absolute gravity determinations (properly weighted) seems eminently reasonable.

SIGMUND HAMMER

CONTRIBUTORS



JACK DE MENT

JACK DE MENT. Research Chemist and Head, Fluorescence Laboratories, Portland, Oregon. Born in 1920, Mr. De Ment was educated at Reed College in Portland, Oregon. In 1941 he was chemist and metallurgist for the Montana Assay Offices, and in 1942 chemist and assistant spectroscopist for the Charlton Laboratories, both in Portland. Since 1940, associate editor, the *Mineralogist* magazine. Mr. De Ment has been head of the Fluorescence Laboratories in Portland since 1942, specializing in luminescence, ultraviolet light and uranium chemistry and mineralogy. He is affiliated with a dozen scientific and professional organizations, including The Chemical Society (London), The Electrochemical Society, Amer. Chem. Soc., and others. He is author or coauthor of ten books on his specialities, and has published about 300 papers and reports in foreign and domestic journals. During the summer of 1946 he was consultant to the secretary of war at Bikini Atoll (the atomic bomb tests).

EUGENE FROWE

Eugene Frowe received a degree of Bachelor of Arts in Physics from the University of Kansas in 1937. After a year's graduate study, he was employed by the Coastal Oil Finding Company on a gravity party, where he remained until 1941 when he returned to the University of Kansas to complete the Master's degree. In July of the same year he joined the staff of the Naval Ordnance Laboratory in Washington, D. C., where he devoted most of his time to research in the magnetic properties of ships. In 1945 he accepted a position in the laboratory of the Robert H. Ray Company, where he is still employed. He is a member of the Society of Exploration Geophysicists.

HOLLAND C. MCCARVER

HOLLAND C. MCCARVER attended the University of Texas from 1931 to 1937, majoring first in business administration and then in geology. He was employed in 1937 by Geophysical Service Inc., and remained with that company until January 1944 when he joined the Seaboard Oil Company of Delaware as Chief Geophysicist. He is a member of the Society of Exploration Geophysicists, the American Association of Petroleum Geologists, and the Dallas Geological Society.

Photographs and biographies of contributors to this issue not appearing above have been published previously, as follows: D. C. Skeels, Vol. VII, No. 4, p. 425 (October 1942); C. Y. Fu, Vol. XI, No. 1, p. 105 (January 1946); L. L. Nettleton, Vol. VI, No. 3, p. 303 (July 1941).

THE SOCIETY ROUND TABLE

ANNOUNCEMENT OF THE SEVENTEENTH ANNUAL MEETING OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS

The 17th annual meeting of the Society of Exploration Geophysicists will be held at the Biltmore Hotel, Los Angeles, California, on March 25–27, 1947. As in previous years, this meeting will be held jointly with the annual sessions of the A.A.P.G. and S.E.P.M. Thus the 32nd annual meeting of the American Association of Petroleum Geologists will be held March 24–27, while the 21st annual meeting of the Society of Economic Paleontologists and Mineralogists will be held on March 26 and 27.

Attention Please

Ten years ago—back there in 1937—the Biltmore Hotel placed its entire aggregate of 1,500 rooms at the disposal of the joint meeting and urged the acceptance without charge of all space required for technical sessions, committee meetings, and exhibits. Those were the days when California was called the land of free milk and honey. Today, after extensive negotiations by the Housing Committee of the Pacific Section of the A.A.P.G., the Biltmore Hotel allows the joint convention a small total of 250 rooms for an anticipated combined attendace of 1,500–1,800 and will charge about $1,500 for the essential meeting rooms. Thus, since the Biltmore will house only one out of every four or five persons attending the convention, it will be necessary to utilize many other hotels. Obviously, the problem of such a complicated housing situation can be most effectively handled by a single Hotel and Housing Committee which has been set up by the Pacific Section of the A.A.P.G. We sincerely appreciate the fact that this special committee offers to assume the responsibility for your reservation your assignment to a hotel, procurement of required advance deposit, plus the confirmation of your reservation. This local committee is anxious to do a good job. Its big one hope is that 75%–80% of attending members, wives, and guests who do not obtain reservations at the Biltmore Hotel will be those hardy folks with the characteristic grin. California members requiring reservations will be assigned to hotels other than the Biltmore.

An excellent technical program, instructive field trips, and plenty of opportunity for entertainment will combine to make this a really good meeting.

A modest registration fee will be charged to assist in defraying the costs of the convention.

S.E.G. Technical Program

Sufficient commitments have already been made by prospective authors to insure well filled and widely diversified technical sessions as you will recognize in the following very general description.

There will be several papers setting forth case histories for producing fields in California as well as in various Mid-continent areas such as Mississippi, Louisiana, Texas, Oklahoma, and the Rocky Mountains. Incidentally, one of these will be devoted to geochemical work in West Texas. An outline of geophysical activity in Canada may be anticipated as an interesting new feature.

Seismic papers will cover such topics as: the operation of the seismograph under difficult conditions as in the flooded jungle of the tropics in contrast with another paper, setting forth the manner of winter work in the Rocky Mountains; such computing items

as notes on a reflection grading system and a method for applying varying velocity control, etc.; such instrument developments as a water-coupled microphone and description of the seismic recording system used at Bikini Atoll.

Gravimetric operations will be well represented by presentation of new calculation techniques, while in magnetic work one can look forward to a report on the operation of the airborne magnetometer with papers on the related use of shoran and radar as surveying aids. The importance of radioactivity phenomena will be recognized by at least one paper setting forth a new approach in measurement technique.

A special feature of the program will be a joint technical session with the A.A.P.G. on the morning of Wednesday, March 26, when our Society will present three papers to harmonize with the theme for the day, "The Geology of Lands Bordering the Pacific." One of these, "Seismic Exploration in Sumatra," by O. F. Van Beveren, will set forth the problems of operation and supply in flooded jungle; a second "Subsurface Exploration of the Bikini Atoll by the Seismic Refraction Method," by Milton B. Dobrin, will shed some new light on the century old problem of how coral reefs and atolls formed and on the large scale geologic movements that must have taken place throughout the Pacific Basin. The importance of the current advent into open water exploration, particularly along the Louisiana Gulf Coast, will be recognized in the third paper in the joint session, entitled "Historical Outline of Offshore Water Work in the Gulf of Mexico." It is anticipated that this paper will be given by John A. Lester and R. N. Gsell of the Magnolia Petroleum Company.

While ample material seems assured for presentation at the annual meeting, it must be fully appreciated that a much greater number of papers is required to assure a sufficient supply to fill the pages of GEOPHYSICS during the coming year; which means that the current program committees, first announced last July, are still very much interested in receiving your contribution, so please contact any one of these men.

General Chairman

Cecil H. Green, Geophysical Service Inc., 1311 Republic Bank Bldg., Dallas 1, Texas (Vice-President, S.E.G.)

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Milton B. Dobrin, Naval Ordnance Laboratory, Washington, D. C.
Maurice Ewing, Columbia University, New York, New York

Society members will be interested in the following additional information on the convention as obtained from an announcement by the Pacific Section of the American Association of Petroleum Geologists.

A.A.P.G. Technical Program

The program for the annual meeting of the American Association of Petroleum Geologists is designed to present and explore problems encountered by those engaged in exploration in lands adjacent to the Pacific Ocean. It will be initiated Monday evening, March 24, with a discussion of sedimentation in the small, deep basins such as are found on the Pacific Coast. Manley Natland will describe a condition in the Los Angeles Basin in which deep water fauna are found at the edge of deposition in the Puente Sea. This paper is to be followed by K. O. Emery's discussion of "Patterns of Sedimentation on the Continental Shelf off California." This theme will be pursued further on Tuesday afternoon by a series of papers on California in which Harold Hoots will first picture the general geological situation and its relation to the development of the petroleum industry. Then there will be three papers on the genesis and evolution throughout Tertiary time of "The Los Angeles Basin" by Herschel Driver; "The Ventura Basin" by Thomas L. Bailey; and, "The Great Interior Valley" by Glenn Ferguson.

The Tuesday morning session will provide the formalities of the opening of the Annual Meeting, including the presidential addresses and various awards. Two important papers will also be presented at this session. K. C. Heald will give a running account of the highlights of domestic developments in 1946 and L. G. Weeks will treat foreign developments in the same manner. A paper on "The Petroliferous Provinces of Washington and Oregon" will wind up the day's program.

Wednesday will be devoted to discussions of the geology of lands bordering the Pacific. Professor Walter H. Bucher will set the stage for this with his discussion of the "Geologic Framework of the Pacific." This will be followed by papers on China by Carlton D. Hulin; The Philippines by Grant W. Corby; Japan by Charles W. Chesterman; Petroleum Production and Resources of Japan by David Cerkel and J. L. Williams; New Zealand by Frank Turner; Central America by Wendell P. Woodring; Eastern Peru and Ecuador by Bernhard Kummel; Coastal Oil Fields of Peru by A. Lyndon Bell; and Chile by Glen M. Ruby. The geophysicists are planning no separate technical session on Wednesday but are providing two and possibly three papers to be presented Wednesday morning at the combined session. These will be of equal interest to geologists and geophysicists. One of them is "Geophysical Work in the East Indies" by O. F. Van Beveren.

Overthrusting is a condition met very frequently and in widely separated areas by geologists in Pacific regions. Wednesday evening is to be dedicated to this problem. Theodore A. Link will guide the symposium and lead off with a discussion of overthrusting in Alberta. Edward C. H. Lammers will discuss overthrusting along the Santa Clara Valley in California where many oil fields exist both above and below the thrust planes, and Donald LeRoy Blackstone, Jr., will discuss overthrusting in Rocky Mountain petroliferous provinces.

Thursday will be devoted to domestic, descriptive and development papers. Al-

ready a number of these have been arranged through the aid of the Publications Committee with its widespread membership and their resultant familiarity with interesting developments and the men best qualified to present them. There will be a variety of papers from Texas, Louisiana, Florida, Oklahoma, New Mexico, the Rocky Mountain States and others. A paper by L. G. Weeks entitled "Paleogeographies of South America" has been just received and accepted for inclusion in the program, but the time of its presentation has not been determined.

GENERAL OUTLINE OF JOINT PROGRAM

March 23 (Sunday)

	A.A.P.G.	Research Committee Meeting

March 24 (Monday)

Morning		Joint Registration
	A.A.P.G.	Committee Meetings
Afternoon		Joint Field Trip (Rancho LaBrea Fossil Pits and Museum)
Night	A.A.P.G.	Open Session (Tertiary and Recent Sedimentation; A Symposium)

March 25 (Tuesday)

Morning		Joint Session (S.E.G., A.A.P.G., S.E.P.M. Presidential Addresses and Awards; Reviews)
Afternoon	S.E.G.	Business Meeting and Technical Session (Miscellaneous Topics)
	A.A.P.G.	Technical Session (California Petroliferous Basins)

March 26 (Wednesday)

Morning		Joint Technical Session (S.E.G. and A.A.P.G. papers on Geophysics and Geology in Foreign Lands Bordering the Pacific)
	A.A.P.G.	Business Meeting
	S.E.P.M.	Technical Session (California Stratigraphy)
Afternoon	S.E.G.	Field Trip (California Institute of Tech. and Seismological Lab.)
	A.A.P.G.	Technical Session (Geology of Foreign Lands Bordering the Pacific)
	S.E.P.M.	Technical Session (General Paleontology)
Night		Open Session (Thrust Faulting Symposium)

March 27 (Thursday)

Morning	S.E.G.	Technical Session (Case History Type Papers)
	A.A.P.G.	Technical Session (Geology and Developments in Midcontinent, Gulf Coast, and Rocky Mountains)
	S.E.P.M.	Technical Session (Symposium on Sedimentary Lithology)

Afternoon	S.E.G.	Technical Session (Miscellaneous Topics)
	A.A.P.G.	Technical Session (Geology and Developments in Midcontinent, Gulf Coast, and Rocky Mountains)
Night		Dinner-Dance

March 28–30 (Friday–Sunday)

	A.A.P.G.	Three-day field trip (Ventura, Santa Maria, Bakersfield)

Field Trips

1. Dr. Chester Stock of the California Institute of Technology will conduct a field trip to the LaBrea Fossil Pits and the Los Angeles Museum on the afternoon of Monday, March 24.
2. The Society of Exploration Geophysicists is planning a trip to the California Institute of Technology and its Seismological Laboratory in Pasadena on the afternoon of Wednesday, March 26.
3. A post-Convention field trip is scheduled to leave 9 A.M. Friday, March 28, returning to Los Angeles late Sunday afternoon March 30. The first day will cover structural and stratigraphic features of the Aliso Canyon Field, the Santa Clara Valley, and the Ventura Avenue Field. Those desiring to return to Los Angeles at the end of the first day's tour may do so from Ventura.

   Friday night will be spent at Santa Maria. Saturday morning the Santa Maria area will be studied and in the afternoon the party will leave for Bakersfield via the Cuyama Valley; the San Andreas Rift and the Midway-Sunset district will be viewed enroute. Saturday night will be spent at Bakersfield. On Sunday, fields of the west side and central portion of the southern San Joaquin Valley will be visited and the return trip to Los Angeles will be made via the Ridge Route.

   Transportation costs for the three day trip will be prorated and paid by each person attending. In view of transportation requirements and the limited hotel accommodations in both Santa Maria and Bakersfield it is absolutely essential that first reservations be made by those planning on this trip. Those interested in this post-convention field trip should not fail to indicate their wishes on the reservation form provided for that purpose.

Exhibits

Desirable advertising space for exhibits of equipment, maps, and services used in petroleum exploration is available in the Foyer, at the entrance to the Technical meetings. Parties interested in purchasing space and arranging for exhibits should write immediately to W. P. Winham, 605 West Olympic Boulevard, Los Angeles, California.

Entertainment

The Dinner Dance in the Biltmore Bowl on Thursday night, and the ladies tea on Tuesday afternoon constitute the only planned entertainment on the program.

Tuesday night, with no technical meeting, is available for those who wish to plan entertainment. Those desiring assistance in obtaining reservations for The Drunkard

(lots of fun) for Tuesday night, or for Earl Carroll's Night Club or the Cocoanut Grove (Ambassador Hotel) for Tuesday or other nights, should so indicate on the enclosed Reservation form.

Ladies Entertainment

Entertainment for visiting ladies is being planned by a local group under the leadership of Mrs. Carroll M. Wagner. A tea, sponsored by Mrs. Earl B. Noble, will be held at the Avila Adobe in Calle Olvera at 3:00–5:30 Tuesday afternoon, March 25. The Avila Adobe is the oldest house in Los Angeles and one of the historic spots of the city. Its setting in the midst of old Spanish Los Angeles will be pleasing to those who still can imagine being stirred to romance by Spanish music and a gay Caballero.

Other entertainment for ladies will be provided in accordance with existing facilities and the indicated wishes of those who plan to attend. Below is a list of events which, according to present tentative plans, will be available within limits. The indication of your wishes on the enclosed Reservation form will necessarily constitute a reservation, and will serve as the basis of definite arrangements. You will be requested to purchase your tickets when you register upon arrival at the convention.

Event	*Time*	*Cost*
Broadcast, "Queen for a Day"	Thursday 11:30 A.M.	None except lunch
Sightseeing trip to City, studios and Westwood Village with lunch at the beach	Wednesday all day	$7.50
The Turnabout Theatre	Wednesday evening	$2.40

Hotels and Housing

The Hotels and Housing Committee has obtained commitments for comfortable rooms from sixteen of the better and most conveniently located hotels. These commitments may be converted into definite reservations only to the extent that those expecting to attend meet the requirements indicated herein.

Fill out your Reservation form, attach your personal check required by the hotel as an advance deposit for your room, and mail on or before February 25th. Checks for $5.00 per person should be made payable to V. W. Vandiver, Hotels Chairman. Hotel reservations to be handled by the Hotels and Housing Committee will close on March 1.

Those who can and wish to stay in private homes are encouraged to do so.

Try to avoid requesting a single room. If possible, team up with somebody else and request a double room.

Your arrival on Sunday March 23 will save you much confusion and will relieve the inevitable congestion expected on Monday, March 24.

Los Angeles Hotels*

Biltmore (Headquarters)	$4.50 and up, Single
	$6.50 to $10.00, Double
Alexandria	$5.00 to $7.00, Double (1 bed)
	$6.00 to $7.00, Double (twin beds)
	$7.00 to $8.00, Triple (three beds)
	$7.00 to $8.00, Triple (two beds)
Ambassador	No rates quoted
Chapman Park	No rates quoted (All twin beds)

Clark	$6.00 to $8.00 daily
Commodore	$2.50 to $3.50 daily
Embassy	$3.00 to $4.00 daily
Figueroa	$3.50 daily (All twin beds)
Hayward	$3.50, Single $5.50, Double
Lankershim	$3.85 to $5.50 (All double and twin beds)
Mayfair	$3.85 daily (twin beds)
Rosslyn	$4.00 to $6.00 (Double and twins) $4.50 to $7.00 (Triples)
San Carlos	$4.00 daily, single or double
Stillwell	$3.00 to $4.00 daily
St. Paul	$3.00 to $4.00 daily
Town House	Approximately $18.50 daily
Teris	$3.00 to $4.00 daily

* All rates are subject to change.

Correspondence addressed to any of the above hotels will be referred directly to our Hotels and Housing Committee.

Those who prefer auto courts, or hotels other than those listed above, are privileged to write at once directly to these establishments for reservations.

Desirable Motor Hotels	*Address*	*Comment*
El Adobe Hotel (Attn: Mr. Nelson, Mgr.)	800 W. Garvey Monterey Park	Have several apartments requiring 3 or 4 persons $3.00 per person.

Deposit for one day required 15 days in advance.

Pueblo de Los Angeles	1750 Colorado Blvd. Eagle Rock 41 California	Cottages with double beds Single (2 persons) $ 5.00 Double (4 persons) 8.00 Triple (6 persons) 13.00

One day deposit required three weeks in advance.

Alberts Motel	1460 Colorado Blvd. Eagle Rock 41 California	Room for two $3.00 Room for three 4.00 Room for four 8.50

One day deposit required 30 days in advance.

Grand Motel (Mrs. Smock, Mgr.)	3321 Colorado Blvd. Pasadena	Room for two $2.00 Room for three 3.00 Room for four 4.00

One day deposit required 30 days in advance.

All quoted rates for hotels and Motor Hotels are subject to increase in the immediate future.

Each member will receive a copy of this announcement, with reservation blank, and with minor revisions in the program, in the early part of February.

(The following is a copy only of the reservation form which will be mailed separately to each member early in February. The member is to return that form in a specially marked envelope to Harold W. Hoots, 555 South Flower Street, Los Angeles, California.)

RESERVATION FORM

Read your announcement—then
Fill out and return this form for

YOUR RESERVATIONS

IMPORTANT: Mail this form with your check on or before February 25, 1947.

For Your Hotel Room

I request _____ at _____ Hotel,
(Number and type of rooms; double or twin beds) (Preference)

March _____. Sharing this room with me will be

_____
(Give name of other person or persons)

I (we) arrive on _____ at _____ March _____
(Railroad) (Hour) (Date)

my check for $_____ is attached.
($5.00 per person)

NOTE: Your reservation and attached check must be received by the Committee by March 1, 1947. You should receive confirmation of your reservation and name of Hotel by March 15.

For Field Trips

I wish to attend the following field trips: Check Below

1. Rancho La Brea Fossil Pits and Museum, Monday, March 24 _____
2. California Institute of Technology and its Seismological Laboratory (Geophysicists) _____
3. Ventura, Santa Barbara, Santa Maria, Bakersfield, Los Angeles (March 28–30) _____
   a. To Ventura and return Los Angeles, Friday, March 28 _____
   b. Complete trip (arriving Los Angeles Sunday evening, March 30) _____

GENERAL ENTERTAINMENT

Dinner Dance (Thursday night)—tickets should be purchased and tables should be reserved when you register.

The Drunkard show—Please arrange _____ reservation(s) for me ($2.50 each) for Tuesday night.

Cocoanut Grove (Abassador Hotel)

Please arrange _____ Reservations for me for _____ night (dinner and essentials $6.00–$7.00 per person).

Earl Carroll's Night Club—Please arrange _____ reservation(s) for me for _____ night (average total cost $10.00 per person).

LADIES ENTERTAINMENT

Ladies Tea—Tuesday 3:00–5:30 P.M.

Sight Seeing Trip (Wednesday)—Please make _____ reservation(s) for me ($7.50 each).

"Queen for a Day" Broadcast (Thursday)

Please make _____ reservation(s) for me ($2.40 each).

The Turnabout Theatre (Wednesday night)—Please make _____ reservation(s) for me ($2.40 each).

Your name _____

Address _____

City _____ State _____

IMPORTANT: Mail form on or before February 25, 1947.

NOMINEES FOR 1947–1948 EXECUTIVE COMMITTEE

The following brief biographical sketches are presented in an attempt to acquaint members of the Society with nominees appearing on the official ballot for the coming year. These biographical sketches are the same as were included in the folder mailed with official ballots.

FOR PRESIDENT

CECIL H. GREEN

JOSEPH A. SHARPE

CECIL H. GREEN received the degrees of S.B. and S.M. in Electrical Engineering in 1924 from the Massachusetts Institute of Technology. Until 1926 he was a development engineer in the A. C. Engineering Department, General Electric Company, Schenectady. During this period he also served as an instructor in advanced engineering classes. He then became Research Engineer for Raytheon Manufacturing Company, engaged in the development of Gaseous Discharge rectifier devices. In 1928 he became Development Engineer with Federal Electric Company, finally being placed in charge of the transmitting tube division of the Newark plant. He entered Geophysical Service, Incorporated, in 1930, serving as party chief until 1936 and as district supervisor until 1941 when he was made Vice-President. He is a member of the American Association of Petroleum Geologists and has served on its National Committee on Applications of Geology (1944–1945). He is a member of the Dallas Geological Society, Dallas Petroleum Club, Dallas Petroleum Engineers, Nomads, the American Geophysical Union, and the Society of Exploration Geophysicists (Secretary-Treasurer, 1945–46; Vice President 1946–47).

JOSEPH A. SHARPE received the B.S. degree in physics "with high distinction" from the University of Arizona in 1928, and during the following two years held an instructorship, and pursued graduate studies, at that institution. During this senior year he

became interested in geophysics as a profession through holding a half-time job at the nearby magnetic and siesmograph observatory of the United States Coast & Geodetic Observatory.

In 1930 he went to the University of Wisconsin for further graduate study, and in successive years held a graduate assistantship in physics, University fellowship in physics, research assistantship in geophysics, and a geological department fellowship. He received the Ph.D. degree in 1934 on a thesis subject concerned with deep focus earthquakes which was later published in the Bulletin of the Seismological Society of America. While at the University of Wisconsin, he installed and operated the seismological station maintained by the Department of Geology.

Following this, Dr. Sharpe received an invitation fellowship in geophysics from the Rockefeller Foundation, which he spent in research and study of advanced geophysics at the Massachusetts Institute of Technology. During this period he prepared, with Dr. Andrew Leith, a paper on the geologic significance of deep-focus earthquakes, later published in the Journal of Geology.

Dr. Sharpe accepted a position as research seismologist with the Stanolind Oil & Gas Company and Western Geophysical Company in the summer of 1935, and in 1937 was promoted to the position of chief physicist, in charge of the geophysical laboratory of these organizations. In 1940 he relinquished administrative duties in order to carry on full time research duties on seismic, gravity, and magnetic instruments and methods. Three papers on fundamental seismic processes published in GEOPHYSICS describe some of the results of these investigations.

In the spring of 1945 Dr. Sharpe joined the firm of C. H. Frost Gravimetric Surveys, Inc., as executive vice-president, which is his present position. During the next few months he organized Geophysical Development Corporation, of which he is president, to engage in the development of new geophysical methods and instruments.

Dr. Sharpe is a member of the Delta Chi social fraternity, Tau Beta Pi, Phi Kappa Phi, Sigma Xi, the American Physical Society, The American Mathematical Society, the Seismological Society of America, the American Geophysical Union, the American Institute of Mining and Metallurgical Engineers, the Tulsa Geological Society, the American Association of Petroleum Geologists, on the research committee of which he is serving a three year term, and the Society of Exploration Geophysicists, which he served as Editor during the years 1942–45.

FOR VICE-PRESIDENT

L. L. NETTLETON received his B.S. degree from the University of Idaho in 1918 and his Ph.D. degree, (in Physics) from the University of Wisconsin in 1923. From 1923 to 1928, he was engaged in electrical research and development in the research department of the Union Switch & Signal Company at Swissvale (Pittsburgh) Pa. From 1928 to 1946 he was in the research laboratory of the Gulf Research & Development Company where he had charge of the interpretation and mapping of all gravity work (torsion balance, pendulum and gravimeter) carried out by the Gulf Oil Corporation. In July 1946, he joined Gravity Meter Exploration Company, Houston, Texas, as a partner in the firm.

For some ten years, Dr. Nettleton was a part-time member of the faculty of the University of Pittsburgh and gave a course of lectures on geophysical prospecting; the notes and other material for these lectures developed into his book *Geophysical Prospect-*

ing for Oil published in 1940. Also, he has been much interested in dynamic geology and the relation of geophysics, especially gravity, to geology. This work is best known through his fluid mechanical concept and fluid models of the formation of salt domes. His journal publications include papers on gravity and magnetic prospecting and calculations, relation of gravity to geologic structure, sources of magnetic and density contrasts, mechanics of salt domes and scale models.

Dr. Nettleton is a member of the American Physical Society, American Association of Petroleum Geologists, American Geophysical Union, American Association for the

L. L. NETTLETON

HOMER G. PATRICK

Advancement of Science, Houston Geological Society and of the Society of Exploration Geophysicists, for which he has served as Editor of the society's journal, GEOPHYSICS, for the last two years. Also, he has served as chairman for the Eastern district of the program committee for several annual meetings and as general chairman of the program committee for the 1943 meeting at Ft. Worth.

HOMER G. PATRICK received a B.S. degree in Electrical Engineering from The Rice Institute in 1925. Immediately following graduation he entered the Geophysics Department of the Humble Oil and Refining Company. He served as computer and operator on a refraction seismograph crew from 1925 to 1927. In 1927 he became Party Chief and served in that capacity until 1934. Since 1934 he has been in charge of seismic exploration for Humble Oil and Refining Company. He is a member of the Society of Exploration Geophysicists.

FOR SECRETARY-TREASURER

THOMAS A. MANHART was born in Sedalia, Colorado, May 15, 1908. He received a B.S. degree in Geological Engineering from the Colorado School of Mines in 1930 and

a M.S. degree from that school in 1932. While he was attending the Colorado School of Mines, he spent one summer working with Dr. C. A. Heiland on torsion balance surveys and worked another summer for the Plaines Exploration Company, conducting magnetometer surveys in eastern Colorado.

In 1932, he worked for the Reclamation Service of the Department of Interior in Idaho, and, in 1933, worked for a short time for Shell Oil Company, Inc., in the geophysical department. He was employed by Seismograph Service Corporation, Tulsa, Oklahoma, on August 1, 1933, on one of its field crews and has served in various capacities

THOMAS A. MANHART

B. G. SWAN

with the company—field supervisor in charge of interpretation and field technique in 1935, assistant vice-president in 1938, vice president in 1941 and executive vice president in June, 1945, which position he still holds.

He is a member of American Geophysical Union, Tulsa Geological Society, and Society of Exploration Geophysicists.

B. G. SWAN attended the University of Oklahoma from 1925 to 1929. In July 1929 he accepted a position with Continental Oil Company and served as an observer on a torsion balance field crew, working in West Texas, Kansas, Oklahoma, and southern Alberta, Canada. In January 1931 he was transferred to a seismograph crew, serving as computer until the fall of 1931, when he returned to the University of Oklahoma, where he received his B.S. degree in Geological Engineering in 1932. He resumed employment with Continental Oil Company in October 1932 and served as seismograph computer and party chief until 1937, when he was transferred to the company head quarters office where he has been engaged in interpretative and administrative work to the present date. Mr. Swan is a member of the Society of Exploration Geophysicists and the Ponca City Engineers Club.

FOR EDITOR (1947–49)

M. KING HUBBERT

FREDERICK ROMBERG

M. KING HUBBERT was trained in the University of Chicago in geology, physics and mathematics, receiving a B.S. degree in 1926, an M.S. in 1928 and a Ph.D. in 1937. In addition he did informal work at Columbia University in electronics and theoretical chemistry. During the summer of 1926, he was assistant geologist in the Amarillo district for Amerada Petroleum Corporation, and during 1927 and 1928, he returned to the same company for geological and seismic work. During the period 1928–30, he taught geology and initiated a graduate course in geophysics at the University of Chicago. From 1931 to 1940 he taught geophysics, and structural and engineering geology at Columbia University. During the summer seasons of the same period he worked variously as Geophysicist for the Illinois Geological Survey, and as Associate Geologist for the U. S. Geological Survey. At the outbreak of the war, he joined the Board of Economic Warfare and engaged in studies of world mineral resources. In the fall of 1943, he left the Government to join the staff of the Shell Oil Company as Research Geophysicist, and in June 1945 assumed his present position as Associate Director of Shell Oil Company's newly created department of Exploration and Production Research.

By way of editorial experience, besides being himself an author of a variety of geophysical and geological publications, Hubbert has served on the Papers and Publications Committee of the American Institute of Mining and Metallurgical Engineers, and on the Board of Editors of the Geological Society of America. In addition he has been a frequent referee for various journals of papers submitted for publications.

FREDERICK ROMBERG received his bachelor's degree in Physics from the University of Texas in 1929. He spent three years in the graduate school at Harvard, receiving

his master's degree in Physics there in 1932. In 1929–30 he served as torsion balance observer and seismograph operator and computer with the geophysical department of the Humble Oil and Refining Company, and from 1933 to 1941 he was seismograph computer and party chief with Geophysical Service, Incorporated, engaging in research on methods of computing and interpretation of seismograph data. Since 1941 he has been associated with LaCoste and Romberg, constructing and developing gravity meters. He has published papers in GEOPHYSICS on the interpretation of seismograph and gravity data. He is a member of the American Geophysical Union, Phi Beta Kappa, Sigma Xi, and of the Society of Exploration Geophysicists.

PACIFIC COAST MEETING OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS

The Pacific Coast Section of the S.E.G. held its second annual meeting in Los Angeles on November 7–8, 1946. The program was planned in connection with the Pacific Coast meetings of the A.A.P.G. and the S.E.P.M.

The technical session held Thursday morning, November 7, was opened with brief addresses by several National S.E.G. officers. Mr. Cecil H. Green, National Vice-President, described general plans for the National S.E.G. meeting scheduled the week beginning March 24, 1947 in Los Angeles. Mr. Henry C. Cortes, Past-President of S.E.G. made a forceful plea for geophysical case history publications. Dr. L. L. Nettleton, Editor of GEOPHYSICS, augmented his comments on publications with brief instructions on manuscript preparation.

The meeting featured a symposium on the subject of "Multiple Reflections." Mr. T. P. Ellsworth delivered the lead paper on the subject, describing multiple reflection records obtained in the Sacramento Valley, near Chico, California. The similarity between these results and a theoretical pattern attributed to multiple reflections was explained. Reflection coefficients and other conditions in this area were described as abnormal, but highly favorable for the multiple reflection phenomena observed. Sound paths formed by reflections between the base of weathering and a basalt bed (50 to 200 ft. thick) at a depth approximating 1,500 ft., were logically suggested as energy sources of recorded results. Prepared discussion papers exemplified basic criteria of Mr. Ellsworth's lead paper and gave other observations related to the subject. A brief summary of these discussions statements follows:

(1) Mr. John Sloat, (Union Oil Company of California)—Relationship of record times, move-outs, and character were explained to show special and limiting factors of "reflection echoes." Very large and rarely encountered reflection coefficients are associated with best known "echo" observations.

(2) Mr. J. C. Waterman (Shell Oil Company)—Energy arrivals were illustrated from apparent depths to 10,000 ft. in a locality where basement conditions were established at about 3,000 ft., suggesting multiple reflections between basement and overlying strata, or basement and surface.

(3) Mr. W. D. Cartwright (Tidewater-Associated Oil Company)—Recorded apparent reflection energies at times greater than established basement reflections were explained as (1) multiple reflections, (2) stray pulses from stratification within the basement or (3) basement contact at two levels (concave surface).

(4) Mr. Frank Ittner (Superior Oil Company)—The reflection coefficient in the Chico area (area covered by Mr. T. P. Ellsworth's lead paper) was determined to be 25% at the sediment-basalt contact from a well shooting survey. A well detector, at variable depths, consistently recorded a burst of energy .450 seconds later than the first break. This interval was calculated as twice the time interval between basalt and surface. The second impulse was presumed to be reflected from the basalt and the surface before traveling to the well seismometer.

(5) Mr. C. H. Johnson (General Petroleum Corporation—Time interval correlations between multiple and primary reflections from a shallow basalt horizon were illustrated, showing good agreement between observed data and theoretical considerations.

(6) Mr. O. C. Lester, Jr. (Amerada Petroleum Corporation)—An experiment was described which was planned for the specific purpose of obtaining surface reflections. The series of tests included a region where the surface was water saturated and also an area where excellent shallow reflections were obtained. In no case were surface reflections in evidence.

(7) Mr. Dean Walling (Western Geophysical Company)—Multiple reflections are known to have been observed under certain unusual conditions but similar appearing phenomena could also be attributed to transverse waves, reflected refractions, earth tremors and other sources. Limitations in differentiating between real and multiple reflections were briefly mentioned.

(8) Dr. C. Y. Fu (California Institute of Technology) commented on the fact that calculated reflection coefficients are based on mathematical expressions derived from the theory of continuous waves and these may not be correct for the wave pulses of reflection shooting.

Additional prepared discussions by Mr. C. H. Dix (United Geophysical Company) and a joint statement by Mr. F. J. Agnich and Mr. E. J. Stulken (Geophysical Service, Inc.) were not presented because of lack of meeting time.

The final paper of the morning technical session was "The Case History, Wasco Field, California" by E. L. Erickson. Early geophysical work on this small deep structural feature was described. Geophysical maps prior to well development were compared to later maps based on well control. Excellent quality data and detail shooting during development were described as important factors in the resulting accurate geophysical interpretation.

A travelog discourse on "Bikini Atom Bomb Experiments" was given by Mr. R. B. Moran, Jr. during the Thursday afternoon A.A.P.G. meeting. This paper was not inincluded in the morning technical session because of time limitations. The paper titled "Correlation Record Grading" by Mr. Phil P. Gaby was postponed for presentation at the National S.E.G. meeting.

An informal noon luncheon attended jointly by the three technical societies was held following the S.E.G. morning meeting. Principal speaker at this luncheon meeting was Mr. E. B. Noble, National A.A.P.G. President, who discussed "Selected Research Problems for A.A.P.G. Sponsorship."

The balance of the two day session featured papers under A.A.P.G. sponsorship which were of mutual interest to all exploration geologists and geophysicists.

The S.E.G. meeting was attended by about one hundred twenty members. Mr.

C. H. Dresbach and Mr. Phil P. Gaby, acting by previous appointment, instigated plans for the meeting, Mr. E. H. Vallat, S.E.G. Area Representative of the Pacific Coast and Mr. C. H. Dresbach, Program Committee Chairman, directed activity which resulted in a highly successful and interesting meeting and also established an organization for sharing the responsibilities of the National S.E.G. meeting in Los Angeles, March 24, 1947.

APPLICATIONS FOR MEMBERSHIP APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it to the Secretary within thirty days. (Names of sponsors are placed beneath the name of each nominee.)

ACTIVE

Gordon I. Atwater
J. W. Hoover, Neal J. Smith, Jos. B. Hudson

Roscoe Curtis Barber
J. H. Swartz, R. Henquet, E. F. Stratton

Adelbert Barry
W. M. Rust, Jr., D. H. Gardner, W. D. Mounce

Prabhat Kumar Bhattacharya
Beno Gutenberg, C. Y. Fu, Hugo Benioff

Charles Henry Blanchard
B. B. Burroughs, John E. Taylor, J. R. Walker

Gordon Edson Bowler
J. P. Woods, O. C. Clifford, Jr., A. E. McKay

Theodor Henry Braun
W. A. English, Frank Ittner, C. E. Reel

Israel Harding Butt
A. E. McKay, C. H. Hightower, O. C. Clifford, Jr.

Edwin Allen Courtney
J. B. Hudson, Neal Smith, L. I. Brown

George Bowen Davidson
W. B. Raper, Paul E. Nash, Jack W. Peters

Don Gilkson
R. B. Ross, Clyde G. Strachan, Louis W. Gardner

Audio Gray Harvey
H. B. Peacock, E. D. Gaby, C. H. Green

Woodrow Wilson Hawthorne
A. E. McKay, O. C. Clifford, Jr., C. H. Hightower

Karl Otto Heintz
R. R. Thompson, W. M. Rust, Jr., M. A. Arthur

Harold Christian Hougen
Alex Frosch, W. M. Rust, Jr., Frank J. Feagin

Charles LaMothe Hubbard
W. M. Rust, Jr., W. D. Mounce, D. H. Gardner

Creston Cyril Hutchinson
V. L. Jones, C. L. Brownlow, E. J. Handley
William Atlas Longacre
C. M. Marquardt, J. L. Adler (Sec. III-D-1 of Constitution)
James Milton Martin
Paul E. Nash, J. C. Menefee, Henry C. Cortes
James Benjamin McKee
F. Goldstone, O. B. Manes, J. E. Walker
Gregg Ferdinand McReynolds
W. M. Rust, Jr., D. H. Gardner, D. P. Carlton
Robert William Olson
Eugene McDermott, Cecil H. Green, J. E. Jonsson
Lee Brown Park
O. C. Clifford, Jr., A. E. McKay, C. H. Hightower
Edgar Sherman Partain
K. E. Burg, F. Rex Walling, Jr., Paul D. Balbin
Austin Sargent Rogers
R. C. Sweet, John L. Bible, Cecil C. Hinson
Carl Fred Rust
J. P. Minton, D. H. Clewell, C. G. Dahm
Henry Bransford Smithwick
A. E. McKay, O. C. Clifford, Jr., C H Hightower
Robert Lionel Sprague
Cecil E Reel, Horace E Shell, Frank Ittner
Frank Stockton, Jr
W. M. Rust, Jr., W. D. Mounce, R. R. Thompson
Carl Christian Wahl
Frank Ittner, C. E. Reel, H. E. Shell

ASSOCIATE

Byron Warren Beebe
Craig Ferris, F. L. Bishop, Joseph E. Sharpe
Raymond George Cox
Francis A. Roberts (Sec. III-D-1 of Constitution)
Oscar Marlin Crump
A. E. McKay, O. C. Clifford, Jr., C. H. Hightower
Everett Fay Damon
C. M. Ross, F. W. Borman, Andrew Gilmour
Earl Graves
A. E. McKay, O. C. Clifford, Jr., C. H. Hightower
Donald Bruce Heaney
Dean Walling, Dupree McGrady, Robery Dyk
Gerald Wilson Ingle
Cecil C. Hinson, Homer C. Moore, F. L. Bishop
George Wesley Johnson
A. E. McKay, C. H. Hightower, O. C. Clifford, Jr.
Robert Ernest Klabzuba
A. E. McKay, C. H. Hightower, O. C. Clifford, Jr.

William Alan Knox
John Sloat, Dupree McGrady, Dean Walling
Gerrit Kok
N. D. Smith, Jr., F. A. van Melle, K. R. Weatherburn
Frank Marion Mitcham, Jr.
A. A. Hunzicker, H. C. Moore, D. R. Davis
Otto Arthur Poirier
J. W. Hoover, N. J. Smith, Booth Strange
Lawrence Everett Twining
Wesley H. Seifert, D. R. Dobyns, Rex H. White

STUDENT

William Allen, Jr.
H. V. W. Donohoo
Michael Declan Dunn
John H. Hodgson
George David Garland
John H. Hodgson, Arthur Brant
George Donald Hobson
John H. Hodgson, Arthur Brant
Roy Meyrick Price Jones
John H. Hodgson, Arthur Brant
John Alexander MacMillan
John H. Hodgson, Arthur Brant
Rulon Stuart Mahannah
W. S. Levings
Dennis Richard Mett
John H. Hodgson, Arthur Brant
Henry Hiroshi Nogami
R. Maurice Tripp
Beverly W. Robinson
Arthur Brant
Calbert Byron Selmser
John H. Hodgson, Arthur Brant
Samuel Aaron Spencer
W. S. Levings

TRANSFER TO ACTIVE MEMBERSHIP

Price C. Barbour
P. E. Haggerty

RE-INSTATEMENT

J. B. Jackson
W. J. C. Kau
Gerrit W. Postma

STATEMENT OF THE OWNERSHIP, CIRCULATION, ETC., REQUIRED BY THE ACTS OF CONGRESS OF AUGUST 24, 1912, AND MARCH 3, 1933.

of GEOPHYSICS, published quarterly at Menasha, Wisconsin, for January, 1947

State of Oklahoma }ss.
County of Tulsa }

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Colin C. Campbell, who, having been duly sworn according to law, deposes and says that he is the business manager of GEOPHYSICS, and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily paper, the circulation), etc., of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Act of March 3, 1933, embodied in section 537, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business manager are: Publisher, Society of Exploration Geophysicists, P. O. Box 1614, Tulsa, Oklahoma; Editor, Dr. L. L. Nettleton, 1348 M. Esperson Bldg., Houston, Texas; Managing Editor, Dr. L. L. Nettleton, 1348 M. Esperson Bldg., Houston, Texas; Business Manager, Colin C. Campbell, P. O. Box 1614, Tulsa, Oklahoma.

2. That the owner is: Society of Exploration Geophysicists, P. O. Box 1614, Tulsa, Oklahoma; J. J. Jakosky, President, 1063 Gayley Ave., Los Angeles 24, California; Cecil H. Green, Vice-President, 1311 Republic Bank Bldg., Dallas 1, Texas; Henry C. Cortes, Past President, P. O. Box 900, Dallas, Texas; George E. Wagoner, Secretary-Treasurer, Drawer 1739, Shreveport, Louisiana.

3. That the known bondholders, mortgagees, and other security holders owning or holding 1 per cent or more of total amount of bonds, mortgages, or other securities are: None.

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5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the twelve months preceding the date shown above is not required. (This information is required from daily publications only.)

COLIN C. CAMPBELL (Signed)

Sworn to and subscribed before me this 19th day of September 1946.

[SEAL] INA ROGERS (Signed)

(My commisson expires Feb. 15, 1949.)

PERSONAL ITEMS

(Members are requested to forward material for inclusion in PERSONAL ITEMS to C. C. Campbell, P. O. Box 1614, Tulsa, Oklahoma)

A luncheon meeting of Tulsa members of S.E.G. was held in the American Room of Hotel Tulsa on December 4, 1946, for the purpose of discussing with CECIL H. GREEN, Vice-President, the activities of the Society during 1946. R. CLARE COFFIN, assisted by E. V. MCCOLLUM, made all arrangements and presided over the meeting.

Mr. Green reported on the activities of the Executive Committee, pointing out the progress being made by the committee of Henry Cortes and L. L. Nettleton in compiling the Case Histories volume, the work of Miss E. Stiles on the improved Cumulative Index, the efforts of W. M. Rust, Jr. and J. F. Gallie in revamping the Constitution, and the good work of R. S. Jackson and his committee on Student Membership. He also presented a tentative outline of papers to be presented at the Annual Meeting in March.

The possibility of organizing a Tulsa section received much favorable comment.

The following Tulsa members and guests were present: L. Y. Faust, F. L. Bishop, A. B. Bryan, R. W. Gemmer, M. E. Morrow, O. Dimmick, J. F. Anderson, R. B. Ross, T. D. Mayes, E. V. McCollum, Craig Ferris, G. Smith, F. R. Kittredge, M. C. Kiess, G. H. Westby, A. J. Barthelmes, S. Wilcox, G. S. Lambert, R. C. Kendall, R. F. Christy, C. C. Ludwick, R. C. Coffin, K. E. Burg, L. O. Seaman, and F. R. Coryn.

The Houston S.E.G. Committee and about twenty other S.E.G. members met at a luncheon at the Texas State Hotel on December 12 to welcome Cecil H. Green to Houston to hear accounts of his West Coast and Mid-Continent meetings and to discuss the activities of the Society during the remainder of 1946 and the first quarter of 1947. The arrangements for the luncheon were handled by W. J. Osterhoudt, Chairman of the local program committee. The prompt response to the informal telephone announcement of the luncheon was indicated by the attendance of five past presidents of S.E.G. and the present editor. Judging from the pleasure which was derived by all from the mixed program of the Society's business and fun, the Houston group expects to arrange other luncheons during the winter. Several absent members who were on duck or deer hunting expeditions, and a few who were traveling for purposes of work, will be present at the next luncheon.

Mr. Cecil Green reported on the activities of the West Coast and Mid-Continent Committees, and gave all present some pointed advice on the situation of hotel accommodations at Los Angeles. W. M. Rust discussed the current work on the Society's Constitution. L. L. Nettleton reported on the editorial chores, and his aims to make the load easier for his successor.

The following Houston members and guests were present: E. E. Rosaire, L. W. Blau, Frank Goldstone, H. B. Peacock, W. M. Rust, L. L. Nettleton, M. King Hubbert, E. S. Shearer, Roy L. Lay, R. S. Jackson, Earle W. Johnson, Sidney Schafer, Ed

Krieg, George B. Lamb, B. G. Martin, LeRoy Fisher, Derry H. Gardner, Joseph L. Adler, George Carr, A. L. Smith, Sam Rogers, G. R. Johnson, W. C. Kimball, A. P. Wendler, W. J. Osterhoudt.

A. M. EICHELBERGER, JR., formerly of the United Geophysical Company, has joined the staff of the Field Research Laboratories of the Magnolia Petroleum Company in Dallax, Tex.

VOLNEY A. ACHESON, until recently an Underwater Gravity Meter Party Chief for the Carter Oil Company, has accepted a new position as Research Geophysical Engineer with Creole Petroleum Corporation, in Caracas, Venezuela, and may be addressed there at Apartado 889.

JAMES L. MORRIS, Geologist with the Pure Oil Co., is now at Box 2107, Fort Worth, Texas.

F. REX WALLING, JR., Party Chief with Stanolind Oil & Gas Co., has been moved from Milton, Florida to Box 812, Mansfield, Louisiana.

NEIL W. MANN has been transferred to Belem, Para, Brazil (Cx. Postal No. 820), as Seismograph Supervisor for Geophysical Service Inc., for work in the lower Amazon basin.

REX H. WHITE, Party Chief with the Magnolia Petroleum Co. has moved to 417 Redell Street, Garland, Texas.

PIERRE EVRARD, Assistant Professor of Geology at the University of Liege, Brussels, Belgium, is at present on an extended tour of the Belgian Congo for the purpose of testing the application of geophysical methods in prospecting.

CHESTER F. BARNES, formerly associated with the Cosden Petroleum Corporation, has entered private practice as consultant in geology and geophysics, with offices in the Petroleum Building, Big Spring, Texas.

J. R. CORNETT and W. B. SIBLEY, Research Engineers, have been transferred to foreign service by the Seismograph Service Corporation, and at present are stationed at Box 228, Cairo, Egypt.

FRANK SIEGEL, with the Sun Oil Company as computer, has moved from Strathmore, Alberta, Canada to P. O. Box 2831, Beaumont, Texas.

R. H. BURTON has resigned from the Geophysical Department of the Amerada Petroleum Corporation and is now connected with The Southwest Butane Company. His address is Box 601, Big Lake, Texas.

FRANCIS A. HALE, until recently with Geophysical Service, Inc., has accepted a position as Seismologist with Richmond Exploration Co., Caracas, Venezuela, and may be addressed at Sociedad a Camejo 16.

Mrs. FRANCES E. SMITH is now with Kerr-McGee Oil Ind. Inc., Oklahoma City 2, Oklahoma.

CARL W. BLAKEY, Middle-East Supervisor for Seismograph Service Corporation, has been transferred from Haifa, Palestine to Cairo, Egypt, Box 228.

JOHN A. PRANGLIN (Capt.), recently released from active duty with the U. S. Army Engineers, is now with the Halliburton Oil Well Cementing Company in their Electrical Research Department. His address is P. O. Box 2535, Houston 1, Texas.

GERALD H. TEFFT has left the United Geophysical Company to accept a position as geologist with Stanolind Oil and Gas Co. He may be addressed at P. O. Box 660, Tyler, Texas.

C. E. VANORSTRAND is currently located at 320 Walnut Street, Pekin, Ill.

DON C. SHORT has recently returned from foreign service with the United Geophysical Company and is now at the company's headquarters, 595 E. Colorado St., Pasadena, California.

R. MAURICE TRIPP has resigned his position as assistant to the President of the Geotechnical Corporation to open a consulting engineering office. His new address is Trapelo Road, Lincoln, Mass.

JAMES A. LONG, formerly with Stanolind Oil and Gas Company, is now with United Geophysical Company, and presently located at Apartado 1085, Caracas, Venezuela.

C. M. ENGLAND has accepted a new position as geophysicist with National Geophysical Company, and has moved to 906 Electra Avenue, Longview, Texas.

W. GORDON SMITH, Seismologist with Caribbean Petroleum Corporation, has been transferred from Jarrow, Co. Durham, England, to Maracaibo, Venezuela.

P. C. HARRIS, of North American Geophysical Company, has moved to 1854 Kipling, Houston, Texas.

JOHN J. RUPNIK, formerly with the Sun Oil Company, has taken up new duties with Sinclair Prairie Oil Company in Tulsa. His new address is P. O. Box 521 (Geol. Dept.), Tulsa 2, Oklahoma.

MARK C. MALAMPHY may be temporarily addressed at P. O. Box 108, Springbok, Namaqualand, Union of South Africa.

R. H. MANSFIELD has transferred to South America, and may be addressed in care of the United Geophysical Company, Apartado 1085, Caracas, Venezuela.

STUART CRONIN, Geologist with the Pure Oil Co., is now located in Billings, Montana, Box 1398.

LESLIE H. TARRANT, Geophysicist for Anglo-Iranian Oil Co., Ltd. has moved to 73 Parliament Hill, Hampstead, London N.W. 3, England.

N. J. CHRISTIE has transferred to the Tulsa office of United Geophysical Company, located at 822 Thompson Building, Tulsa, Oklahoma.

ALBERT W. MUSGRAVE, who has been vacationing at home since his release from military service, has re-entered the Colorado School of Mines and may be addressed at 1006 13th Street, Golden, Colorado.

ETHEL WARD MCLEMORE may now be addressed at Route 1, Box 104c, Aledo, Texas.

EDWARD G. SCHEMPF, Vice-President and Supervisor with United Geophysical Co., has transferred to company headquarters at 595 Colorado St., Pasadena, California.

GEORGE N. MEADE is currently located at P. O. Box 411, Sulphur, Oklahoma.

CHARLES A. DURHAM has returned to the United States from work in South America with the International Ecuadorean Petroleum Company, and may be addressed at 617 East 43rd Street, Austin, Texas.

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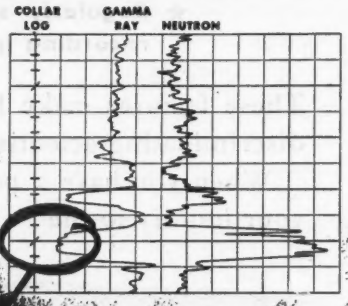

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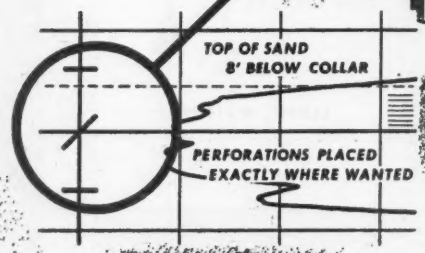

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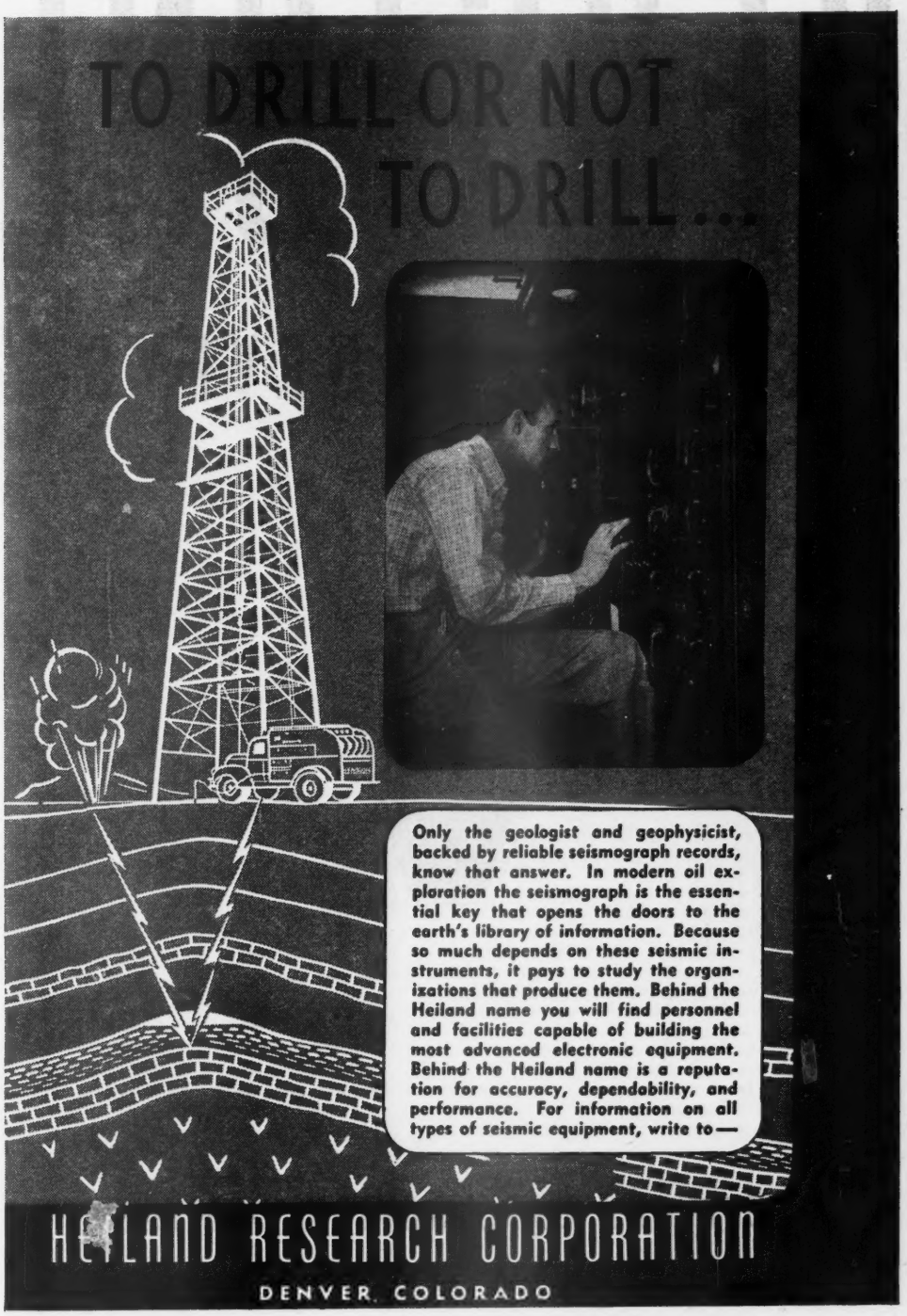
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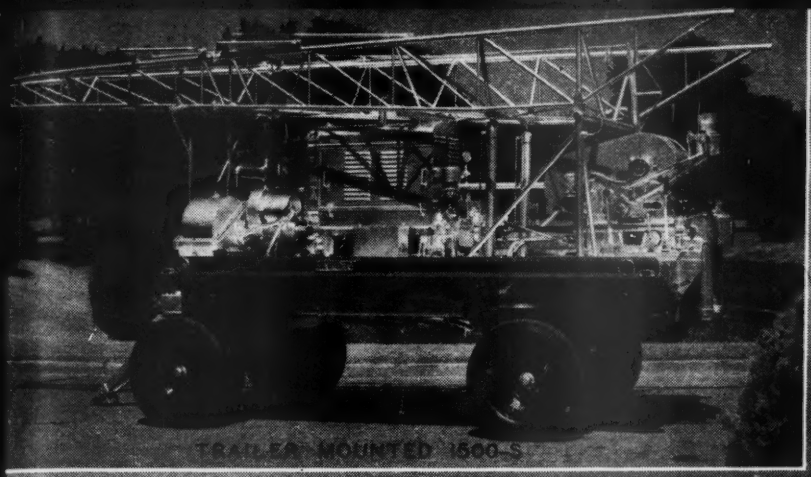

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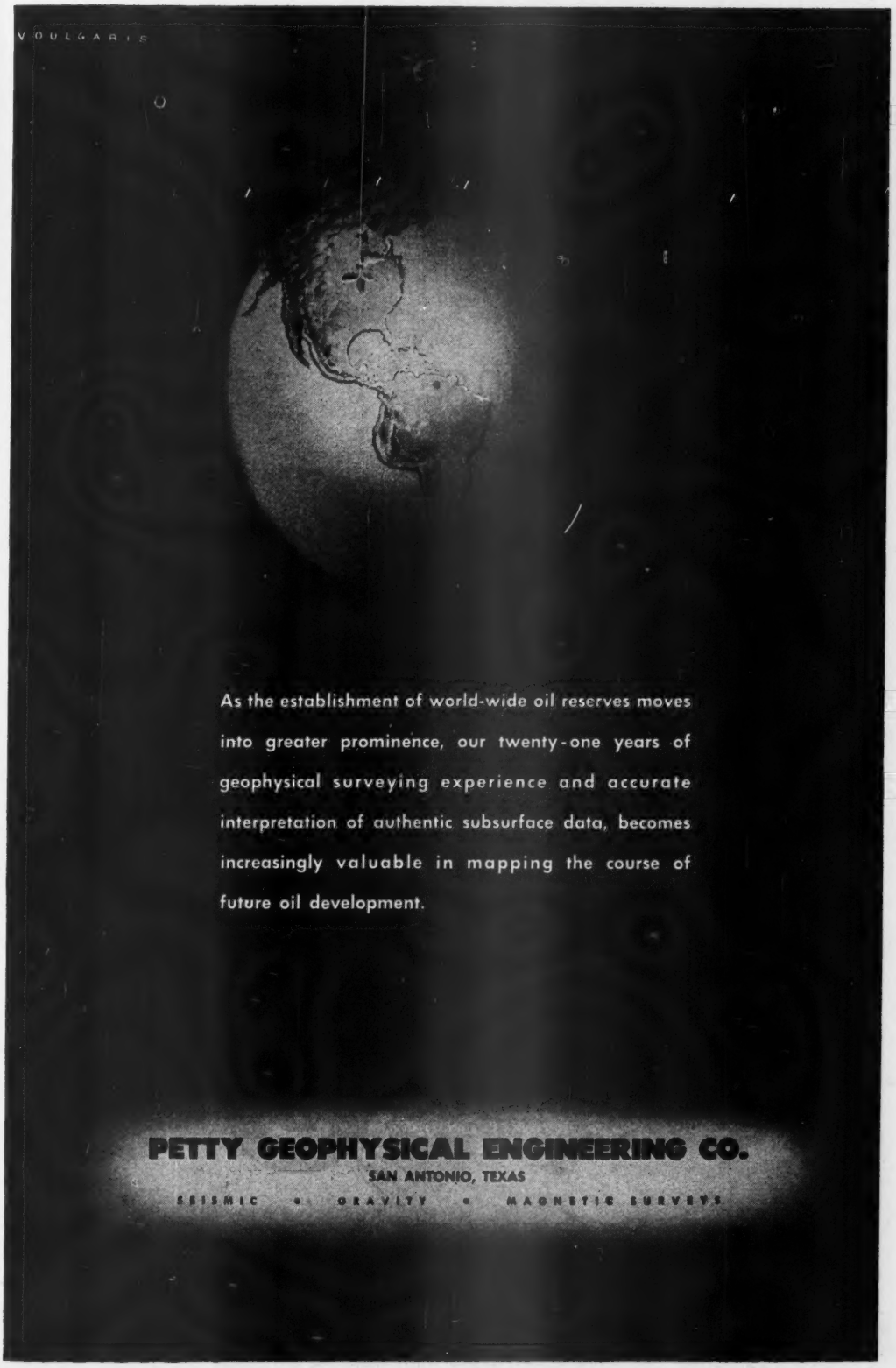
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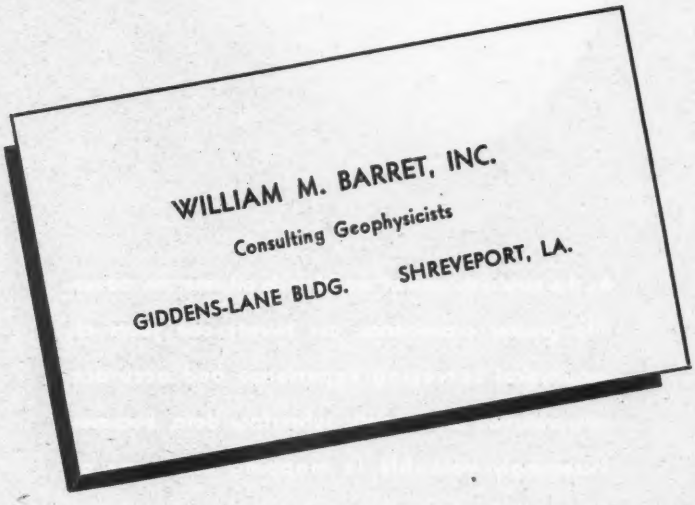

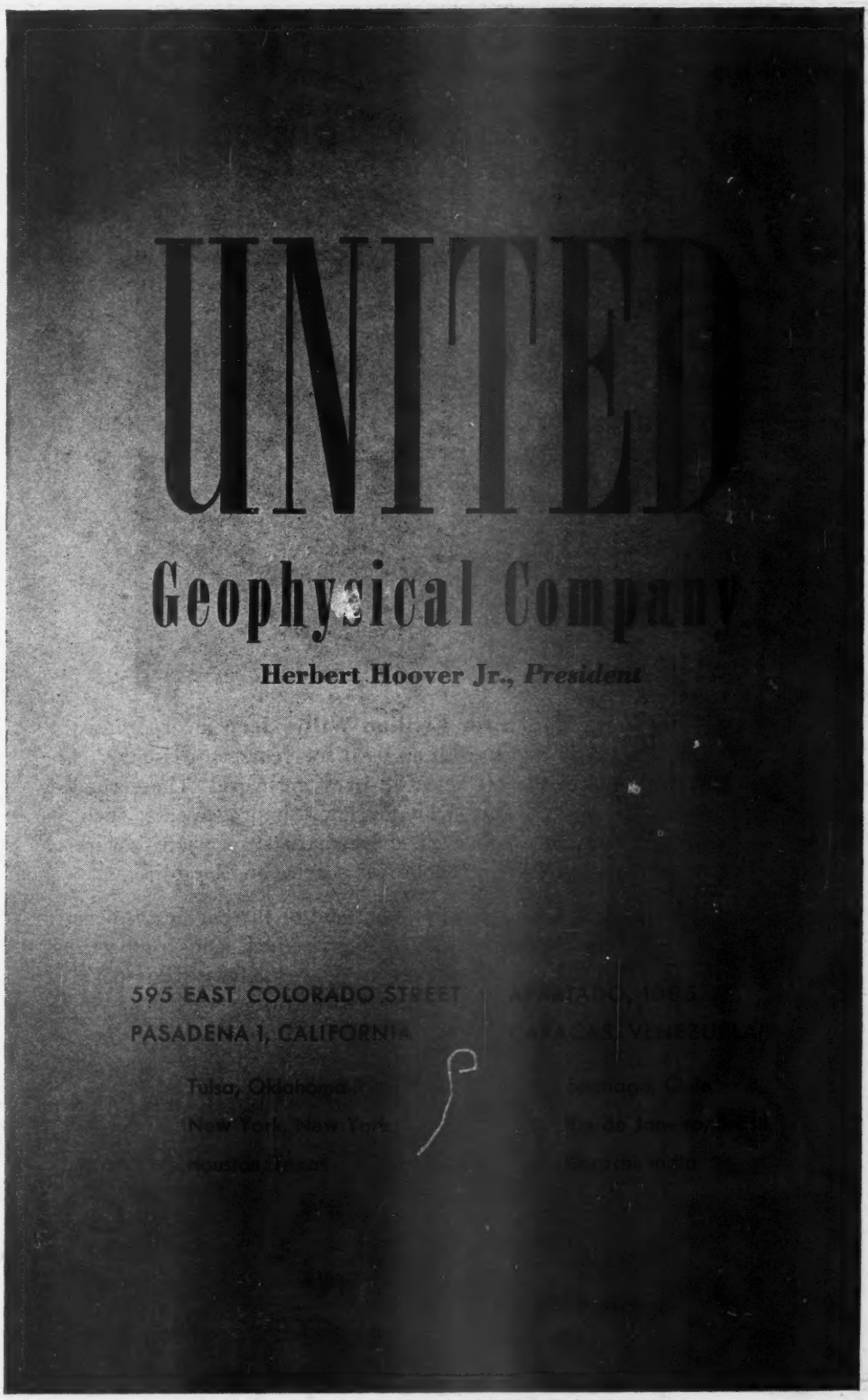
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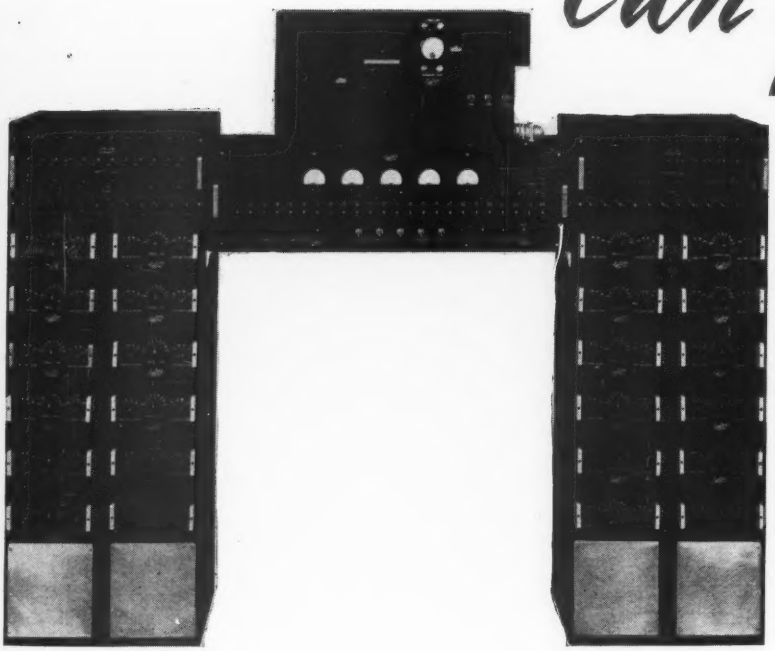

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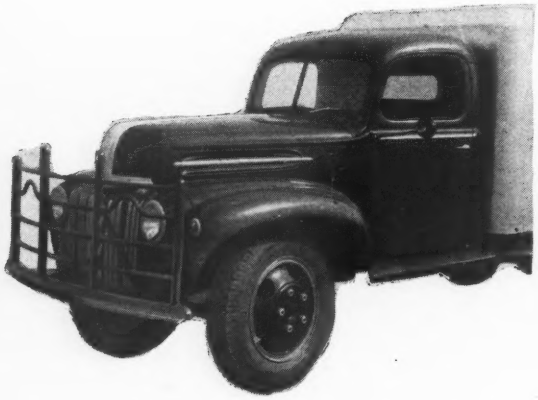

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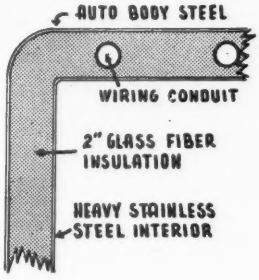

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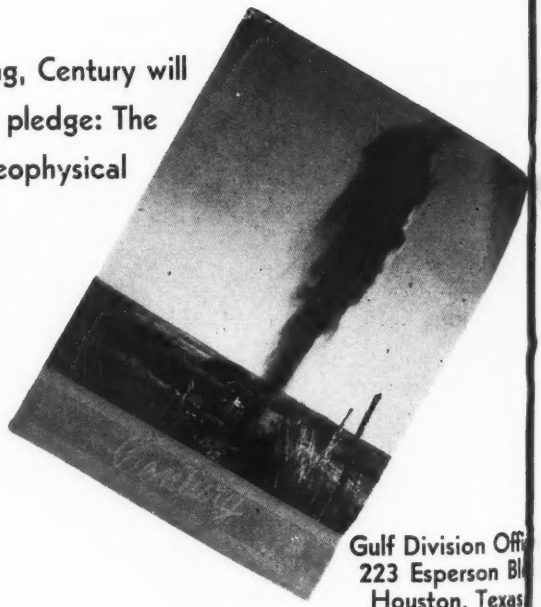

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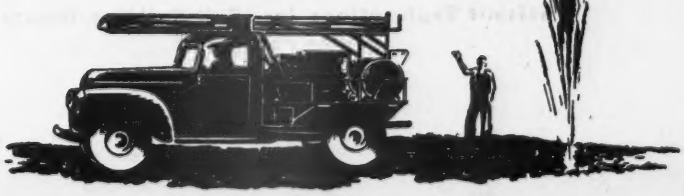

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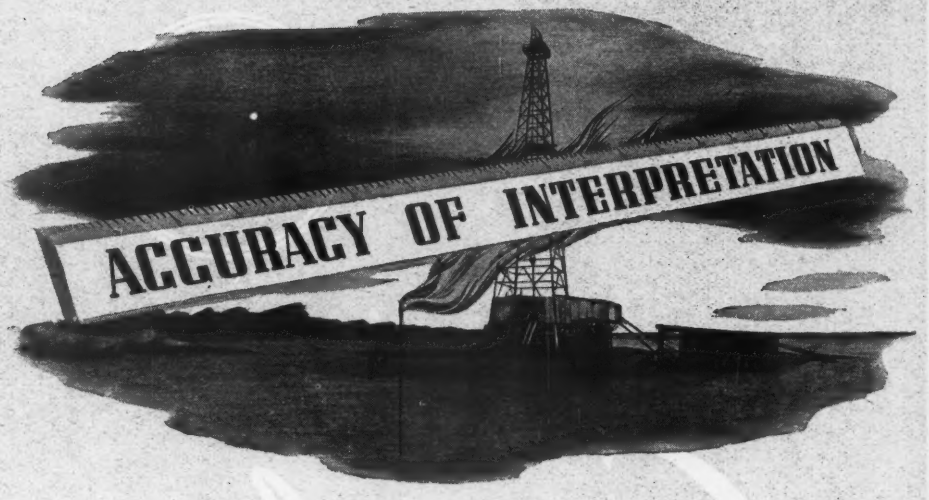

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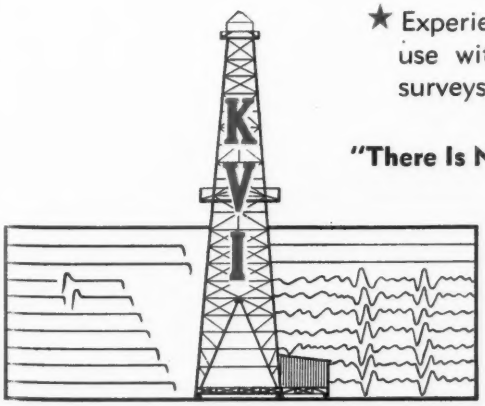

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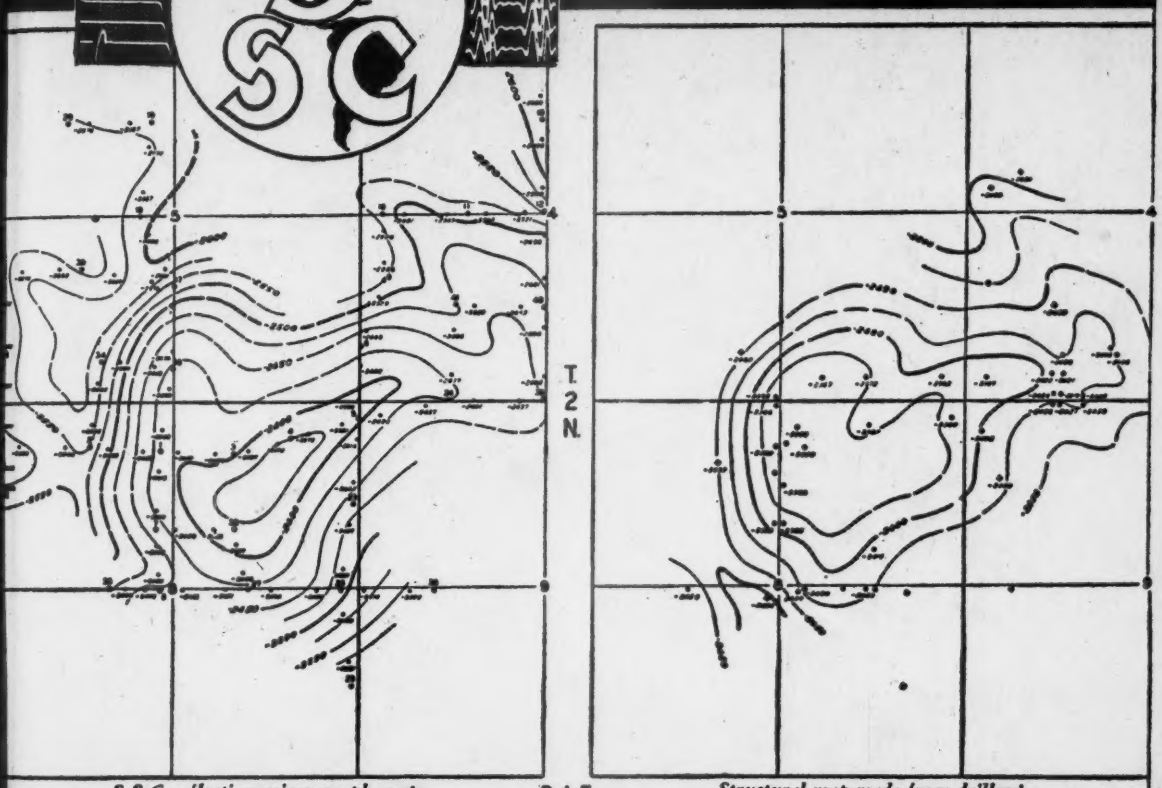

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